The
ENGINEERS' DIGEST

REVIEW OF WORLD ENGINEERING PROGRESS

VOL. XVII No. 9 SEPTEMBER. 1956

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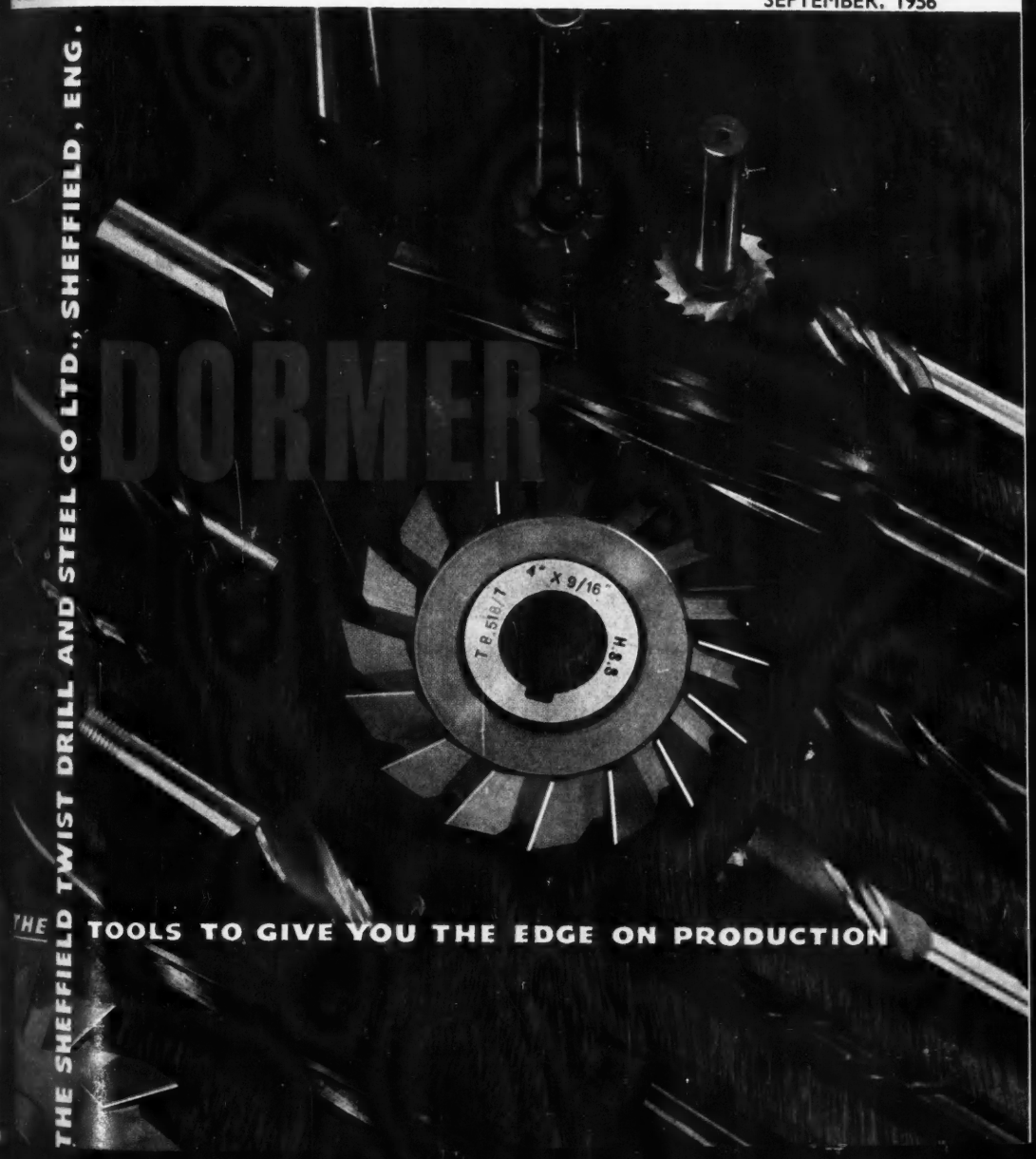
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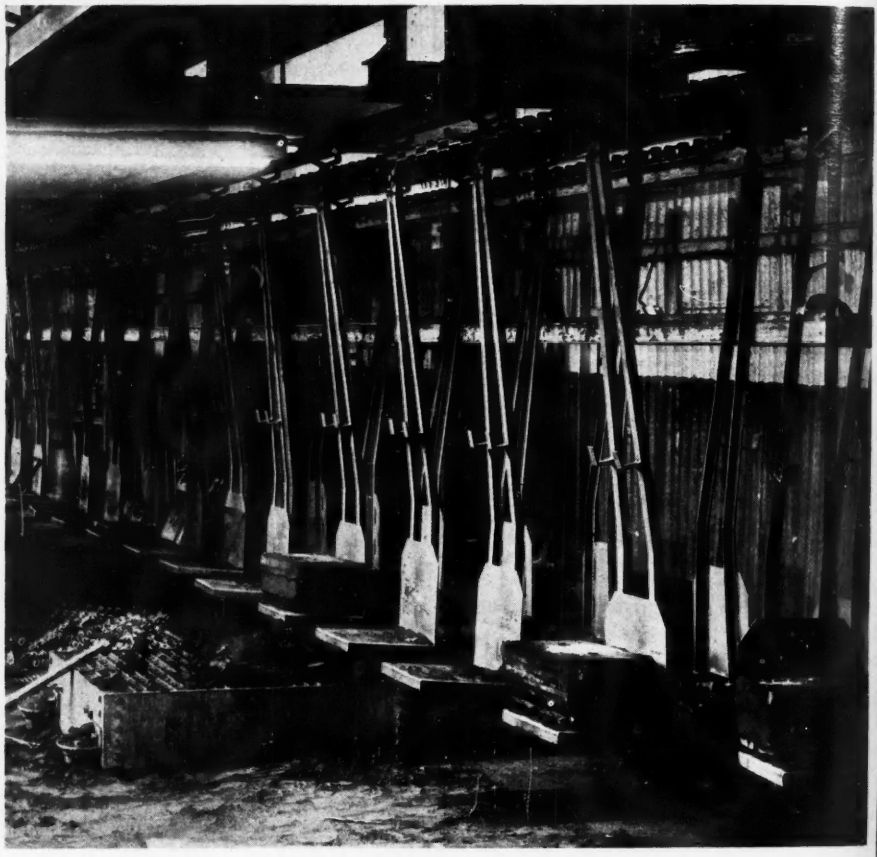

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THE BLUE PAGES

A QUICK GLANCE AT THE LATEST TECHNICAL DEVELOPMENTS THROUGHOUT THE WORLD

● *STEEL FOR HOT PRESS-FORGING DIES*

For hot press-forging dies a new steel has been developed which contains 0·2 to 0·5% carbon, 0·6 to 0·8% manganese, 3·25 to 3·5% molybdenum, 3·0 to 3·25% nickel, and 0·2 to 0·30% silicon. It is claimed that hot press-forging dies of this material have given outstanding performance, and that this steel is exceptionally resistant to heat checking, possesses good impact strength, and is resistant to plastic flow under the press stresses. Moreover, it develops and retains in use a surface hardness which is adequate for minimizing abrasion of the die opening under plastic flow of the metal being forged. An outstanding characteristic claimed is that, when the material is properly heat-treated, the die blocks are soft enough for easy machining, but when put into service they undergo precipitation-hardening at the surface under the influence of heat absorbed from the work, with the development of high surface hardness. This phenomenon continues progressively once the die is put in use and, as the die surface is heated, maximum hardness is developed. Thus, press dies and other hot static work elements produced from this steel possess a surface hardness which minimizes erosion, while the metal, at and adjacent to, the surface is backed by a ductile body which gives excellent shock resistance. The outstanding characteristic of this steel is, however, its resistance to heat cracking. These results are all the more surprising, because it is known that nickel tends to make steels more susceptible to thermal rupture, and that it does not ordinarily tend to confer heat resistance.

● *USE OF ISOTOPES IN STEEL MELTING*

The elements contained in steel baths are usually determined by chemical or spectrographic methods. It has, however, been found that in liquid-metal baths, if the isotope of the element to be examined is added, it mixes with the remaining constituent elements in such a way that, when a change in concentration of the melt with respect to such an element takes place, the diminution in the radiation is directly proportional to the decrease in the element itself. If the element under observation diminishes to half the initial percentage, the radiation of the added isotope of this element similarly amounts to only half the original radiation. In metallurgical methods in which changes of concentration occur, e.g., the conversion of pig-iron into steel or the refining of copper or other metals, an isotope of the element of special interest can be added and the actual analytical content of this element can be deduced directly from the decrease in radiation, provided that the analysis of the starting melt is known, the radiation itself being measured by means of a Geiger counter. It is, of course, necessary to ensure that a clean sample of the metal bath is taken, i.e., that this sample is not contaminated by slag, and that the geometric arrangement of the sample and Geiger counter always remains constant. A typical application of this patented method is the determination of the phosphorus content in a steel melt and hence the observation and control of the burning of the phosphorus. In this case, the phosphorus content is determined in melting Thomas steel in a converter by adding to the melt an isotope of phosphorus, as, for instance, the beta-emitting phosphorus isotope P^{32}.

● *IMPROVED SHOT-BLASTING MATERIAL*

Shot-blasting is finding extensive application for cleaning castings and for the removal of oxidation or rust from metallic surfaces in general. Round shot, however, merely produces a hammering effect and can therefore be used only in such special cases as shot-peening. Particles of broken metal or grit, on the other hand, also have a cutting, shearing, and notching effect, enabling them to penetrate by their edges and especially by their sharp projections into all kinds of depressions on the surface to be treated. A recent patent specification points out that the favourable effect of broken metal particles is reduced by two disadvantages, i.e., (1) the edges and projections are soon knocked or rounded off in the process, so that edged particles become more quickly worn out than round particles; and (2) the edged particles cause considerably more wear and tear on the parts of the centrifugal machine which come into contact with them, especially the centrifugal scoops. To improve conditions, it is suggested that a mixture of round and broken particles should be used, in which case it is claimed that the necessary percussion effect is mainly performed by the round particles, which preserve the blasting machine better because of their rolling movement, while the abrasive action is performed by

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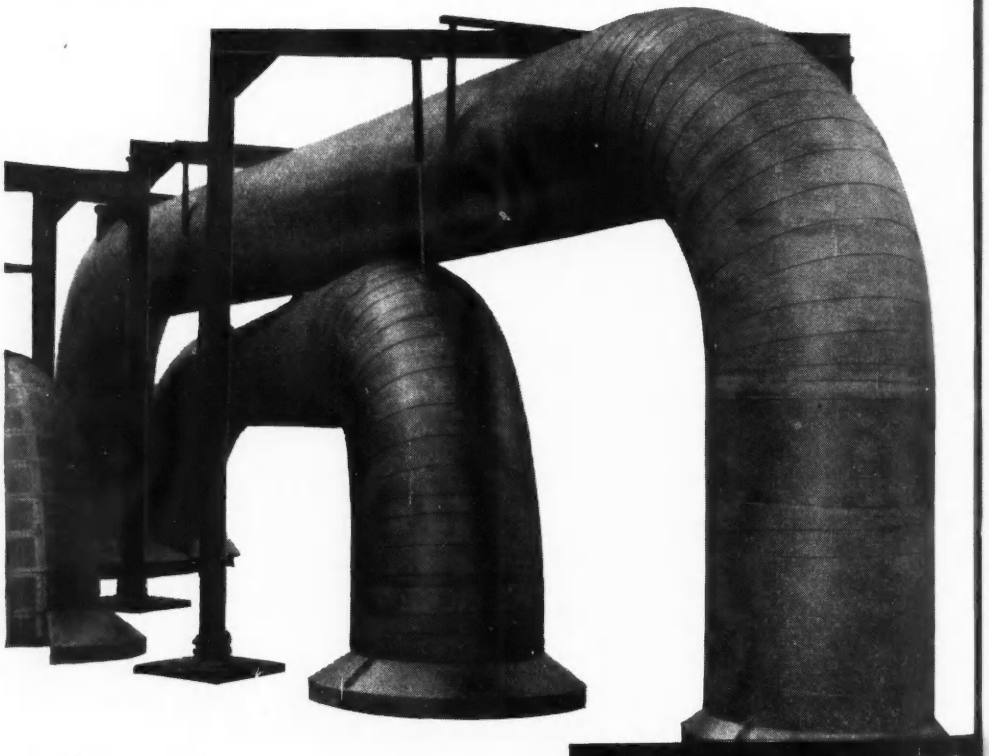

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the broken particles. It is recommended that, in general, the round particles should be smaller than the broken particles, as, for instance, 1 mm and 1·2 mm diameter respectively. It is stated that a mixture of 45% by weight of round particles and 55% of broken particles has a useful life two and a half times that of a material consisting exclusively of broken particles, while wear and tear on the impeller is halved.

● *NEW TYPE OF STRESS-DETECTING DEVICE*

A new stress-detecting device is based upon the fact that a magnetic field which acts on a body of magnetic material is subjected to a variation in magnitude or direction if the body is subjected to a mechanical stress. The magnetic field may be an alternating field produced in a two-pole electromagnet, the poles of which are in contact with the body or are at a very small distance from it. Measurement is carried out by a winding on a detector core, i.e., another two-pole core oriented at right angles to the electromagnet. If, due to tension, torsion, or compression, a mechanical stress arises within the body, the direction of which makes an angle with the magnetic field, the magnetic flux produced by the electromagnet will change its direction. The point at which the poles of the detecting core are located will then have unequal magnetic potentials, so that a signal voltage is produced in the winding of the core. This voltage as a rule is so high that it may be measured by an indicating instrument directly or after slight amplification, the indication being a measure of the mechanical stress present in the material. It is stated that this method can be used for measuring tension in the stationary parts of machines, e.g., roller stands, screw-downs in rolling mills, or beams or struts of bridges and other structures. It may also be used for measuring the torque within shafts or clutches or for the weighing of loads suspended from cranes or of railway wagons or other vehicles.

● *INFRARED RADIATION DETECTOR*

A recent patent specification describes what is claimed to be a unique device for the detection of infrared radiation. In a number of respects the new instrument resembles a light-amplifying device comprising a laminated cell construction in which the laminae are arranged in the manner of an ordinary parallel-plate condenser with a dielectric material between the plates. This dielectric material consists of a lamina of photoconductive material, preferably cadmium sulphide, and another layer of electroluminescent material. If an alternating voltage is applied to the two condenser plates, illumination of the photoconductive layer will alter the distribution of the voltage division across the two individual layers in such a direction as to increase the voltage across the electroluminescent layer. Owing to this increase in voltage, the electroluminescent layer will emit light of a brightness corresponding with the change in the electrical characteristics of the photoconductive layer. The distinguishing characteristic of this infrared radiation detector is that it is sensitive to infrared radiation to the exclusion of any visible radiation, the basic principle being the use of a single crystal of cadmium sulphide, which is sensitive to both visible and infrared radiation, the respective sensitivity being in opposite senses. In other words, when illuminated with visible radiation, its electrical resistance will decrease, whereas, when subjected to infrared radiation, its resistance will increase. As not all cadmium sulphide crystals exhibit this property to an equal degree, it is necessary to select a particular crystal which shows this property to an especially marked extent.

● *MISSING-PULSE DETECTOR FOR TESTING MAGNETRONS*

A new missing-pulse detecting device has been developed for the testing of magnetrons. In radar technique a missing pulse is defined as one which has an energy content less than a specified percentage, usually 70% of normal, at the specified output frequency. Such a deficient pulse may be caused by arcing or "moding" of the magnetron during all or part of a pulse period, moding being defined as an oscillation at other than the specified frequency and ranging from a few hundred to several thousand megacycles away from the operating frequency. An instrument for the detection of missing pulses must respond to pulses of improper frequency, inadequate amplitude, and inadequate pulse width. Two general types of missing pulse detectors seem to be in use at present, these being the direct-cancellation type and the coincidence type. The disadvantage of the former is that its operating adjustments are extremely critical and susceptible to drift with time, while the latter suffers from the shortcoming that it requires a large number of operating adjustments and is not well suited for use by unskilled personnel. It is claimed that the disadvantages of the two types are eliminated in the design of the new missing-pulse detector, which employs a bolometer or a barretter for installation in a wave-guide or coaxial cable. This barretter will convert the magnetron pulse energy into heat, so that its resistance will cyclically vary with the magnetron pulse rate and with its peak power. It is stated that the new instrument is suitable for repetition rates of up to 2000 pulses per second.

Orders keep pouring in...

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a better
mousetrap
and the world
beats a path to your
door. And the saying holds
good whether it be mousetrap or
machine tool, door lock or duplicator,
fishing reel or food mixer, printing plant
or petrol pump. Whatever the product if it
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right price—orders will come pouring in. To-day
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● *CEMENTED CARBIDE MATERIAL FOR TOOLS*

In the conventional hard metals, such as tungsten carbides, cobalt is generally employed as the bonding metal. It is now reported that, by addition to the cobalt either of boron or chromium, or of both in the form of chromium boride, a superior product is obtained. These additions to the cobalt make it possible to sinter the compact at a temperature below 1300°C, sintering temperatures in the region of 1000°C being said to be sufficient. A powdered bonding medium of 5 to 25% chromium, 1·5 to 6% boron, and the remainder cobalt is claimed to be particularly suitable. If such a bonding medium is used in conjunction with tungsten carbide powder, tools can be produced with a high degree of toughness, outstanding resistance to wear, and lasting cutting power. It is reported that a tool sintered at 1000°C, from 78% tungsten carbide, 18% cobalt, 0·6% boron, and 3·4% chromium, exhibits substantially the same cutting power as a material sintered from 94% tungsten carbide and 6% cobalt. This is surprising, since operating temperatures of 900 to 1000°C are observable at the cutting edge of a tool, and it would not therefore be expected that a hard metal sintered at 1000°C would withstand the stresses involved. A further important advantage of the new material is that it can be bonded to the steel carrier without the use of any type of soldering agent. In fact, the material can be sintered firmly to the steel at temperatures which do not injure the steel, so that an unsintered compact can be sintered directly onto the steel. The material is also claimed to be suitable for hot pressing.

● *SHEET MATERIAL FOR LAMINATED CORES*

A recent invention is concerned with a novel method of producing high-grade thin sheet material of low coercivity for laminated cores of transformers, motors, and generators. The basic principle underlying the process is the fact that an iron layer produced electrolytically upon a metal surface has the same crystal structure as that of the surface itself. As the magnetic properties of an iron sheet are related to the orientation of its crystal structure, it is therefore possible to produce a sheet with the desired orientation by electrodeposition of the iron upon a surface having the same structure. This principle is utilized in practice by first preparing such a surface by cold-rolling a thin sheet of gold with a reduction of 95% or more and annealing it at 1000°C for one hour; alternatively, nickel, copper, iron, aluminium, or nickel-iron alloy with 50% nickel can be used. Upon the gold surface a sheet of iron is electrodeposited, and this is then used as a master sheet, after which actual production of the sheet material is carried out by first electrodepositing upon the master sheet a thin layer of tin. Upon this layer an iron sheet is then produced by using an electrolyte of ferrous chloride at a temperature of not less than 50°C and a current density of approximately one ampere per decimetre, until a coating of at least 0·002 in. has been obtained. This latter sheet, which represents the final product, is removed from the master sheet by removing the intervening tin layer by melting. After stripping the sheet from the master sheet in this way the latter can then be used again for the production of additional sheets.

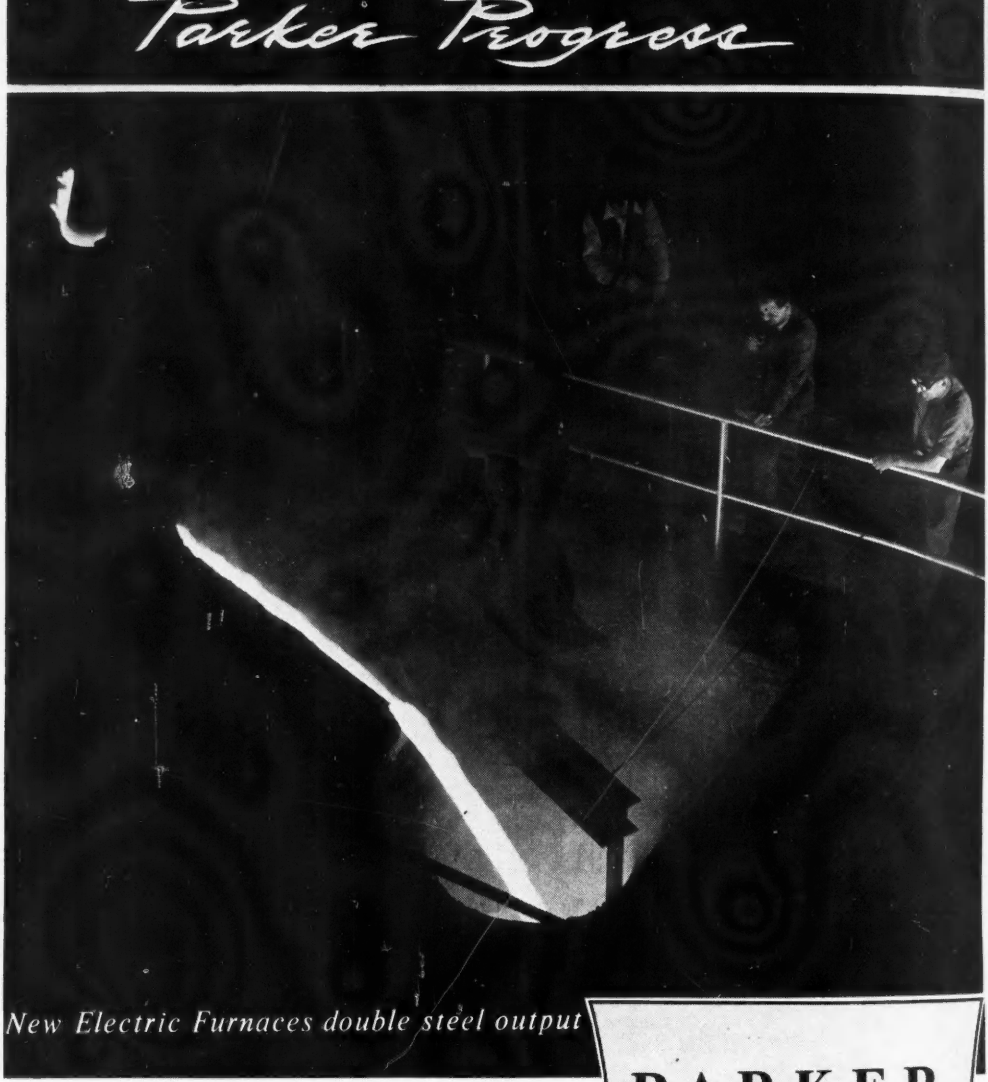
● *ALUMINIUM ALLOYS FOR BEARINGS*

In the past, the principal barrier to the use of aluminium in bearings for ferrous-metal machine parts has been the tendency of aluminium to adhere to the ferrous metal, causing scoring or seizing. Although some aluminium alloys have been developed to overcome this difficulty, their machinability and hardness have been inadequate for some heavy-duty applications. Now, however, the development of a new alloy is reported which will make it possible to construct bearings which are one-third the weight of tin-bronze bearings, which are probably cheaper to produce, and which will perform well under extreme conditions, as they have a much greater resistance to fatigue or to cracking under the pounding action to which bearings are sometimes subjected. In addition, the new alloys are said to be highly resistant to corrosion from the acid constituents of lubricating oils. It is considered that, among other applications, aluminium-alloy bearings will be particularly useful in railways, as they will eliminate hot-boxes caused by overheated journal bearings. They should also eliminate copper penetration, which reduces the strength of steel axles to their breaking point. The new alloy contains from 0·5 to 9·0% silicon, 0·2 to 5·0% cadmium, and 0·1 to 0·5% chromium. Iron, which together with silicon occurs in commercial aluminium, may be present in the alloy in amounts up to 0·5% without causing serious harm. For optimum corrosion resistance, indium may be included in the alloy, in amounts from 0·03 to 0·5%, though preferably from 0·1 to 0·15%.

● *IMPROVING THE WEARABILITY OF GLASS FIBRE*

It has been discovered that the abrasion resistance or wearability of the surfaces of glass fibres can be considerably increased by electrostatic treatment of the glass during fibre-forming operations. Thus, it has been found that, by passing streams of glass from which fibres are drawn through an electrostatic field with a local potential gradient of 10,000 V per inch or

Parker Progress



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more, the flex endurance of fibres grouped together in a strand can be increased from 10 to 150 times or even more, in comparison with untreated fibres. The physical effects of electrostatic treatment are not observable with the naked eye, nor can they usually be detected with an optical microscope. However, electron-microscope photographs of replicas of the treated fibres taken at a magnification of about 20,000 reveal that the surfaces of the fibres are rough or stippled in appearance, with numerous crowded hill-like projections and valleys between, while untreated fibres photographed under identical conditions reveal smooth surfaces. It is reported that, contrary t what might be expected, such surfaces are effective in producing results in wear or abrasion tests which so far can only be attributed to a lowered coefficient of friction at the interfacial contact points of the fibres comprising a strand. Although the theoretical basis for the improved wearability of the roughened glass surfaces is not clearly understood, the results have proven of positive practical value in increasing the wear life of glass fibres subjected to conditions of abrasion between themselves, as well as with other materials. Moreover, these results have been attainable without any loss in the tensile strength of the glass fibres. Hence, it is claimed that the fibres thus treated lend themselves not only to use in textile strands, yarns, cloths, and tyre cords, but also in such products as reinforcing mats or preforms for plastics, moulded fibrous articles, and structural materials.

● *INFLUENCE OF WATER VAPOUR ON HIGH-CURRENT D.C. ARCS*

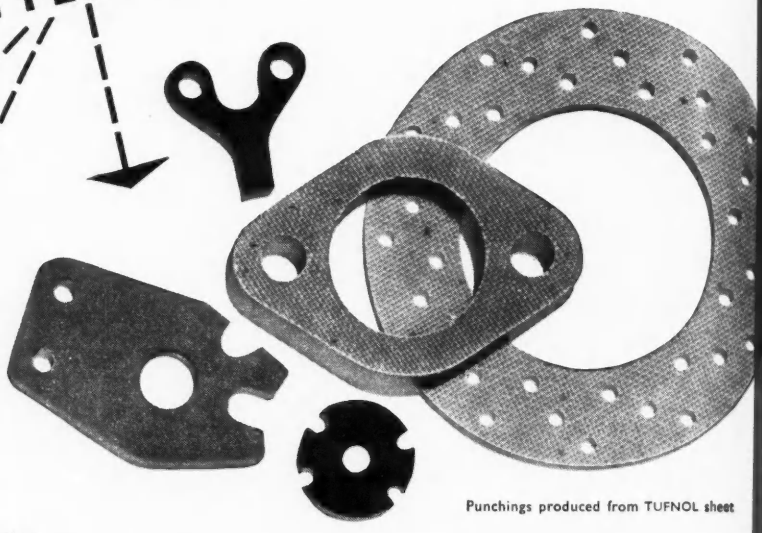
A recent research report deals with the effect of water vapour upon arc characteristics, the objects of this research being to obtain quantitative information to apply to practical problems and to add to the basic knowledge on high-current arcs in gas mixtures. Arcs with direct currents in the range between 20 and 200 A were studied at atmospheric pressure in air containing water vapour in controlled amounts, varying from 0·15 to 100% by volume. For arc electrodes, the materials employed were iron, copper, tungsten, and graphite. Data were taken relating the electrical characteristics and stability of the arc to atmospheric water-vapour content, arc current, and electrode separation and material. It was found that the presence of water vapour causes an increase in arc voltage compared with that for dry air, and that this increase is much greater for electrode materials of iron and copper than for tungsten and graphite. For a 120-A arc with iron electrodes, with a separation of 1 cm in an atmosphere of 100% water vapour, the magnitude of the arc voltage is approximately 170% greater than for a similar arc in air containing 0·15% water vapour by volume, whereas, under similar conditions, using graphite electrodes, only a 13% voltage increase occurs. These voltage increases appear to occur in both the arc column and the electrode drop regions. From an analysis of the results it seems that the differences between the effects of air and water vapour on the arc are derived from the predominant roles of the large specific heats of water vapour and hydrogen and from the great energy-transferring properties of hydrogen attributable to its relatively small mass.

● *MANGANESE-BISMUTH MAGNETS*

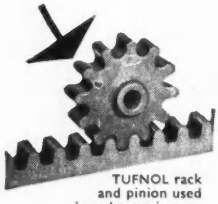
The magnetic properties of manganese-bismuth have been known for years, but hitherto the alloy could not be made of sufficient purity to realize its potential usefulness as a magnet material. A process has now been evolved for the manufacture of high-purity manganese-bismuth powder, which can be moulded and cast into varied forms of permanent magnets. The powder is produced by grinding manganese and bismuth together to an extremely small particle size in an inert atmosphere of helium, the basic purpose of the helium atmosphere being to prevent the powdered material from catching fire spontaneously, as would be the case on exposure to the oxygen in air. The mixture is sealed in a glass vessel under low-pressure helium, and, using precise temperature control, the manganese and bismuth are caused to combine chemically at a temperature slightly below 520°F. The resulting product, which is virtually 100% manganese-bismuth, is then reground to a fine powder, the particle size of which is stated to be 4×10^{-5} in. Finally, the magnetic body is produced by using a plastic binder or matrix which forms the body and keeps the embedded powder particles separated from each other; in addition, since the plastic binder is an electrical insulator, the magnets produced are electrically non-conductive. Manufacture of the magnets to the desired shape can be carried out by casting, moulding, or possibly even extruding. An important step in the manufacture of such magnets is that of effecting orientation of the particles in the plastic by exposing the mass to a powerful magnetic field prior to moulding. It is claimed that magnets produced in this way can be easily drilled, tapped, or cut, the ease depending upon the plastic binder used.

For further information on developments reviewed in THE BLUE PAGES, readers are invited to write to the Editor.

Insulation PLUS strength—with TUFNOL



Punchings produced from TUFNOL sheet



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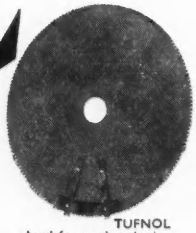

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VOL. XVII No. 9 SEPTEMBER, 1956

The Corrosion of Insulator and Conductor Hardware

By A. W. BARDEEN and J. M. SHEADEL. (*From Power Apparatus and Systems (A.I.E.E.), U.S.A.*, No. 24, June 1956, pp. 491–501, 17 illustrations.)

In this paper, descriptions are given and classifications made of the different types of corrosion observed on the insulator and conductor hardware of power lines, together with remedial measures based on studies extending over more than thirty years.

WET-PROCESS porcelain, as used for high-voltage insulators, is well known for its ability to resist atmospheric corrosion. Insulator assemblies, however, include metal parts which may corrode and limit insulator life in certain contaminated areas.

Only a small percentage of insulators in service is exposed to serious attacks. For normal requirements, the corrosion resistance of malleable iron and steel parts, properly hot-dip-galvanized, has met the required duty. However, for those contaminated atmospheres in certain seacoast and industrialized areas where severe attack on the insulator or conductor hardware may shorten the useful service life, corrosion is of major concern. Although smog is the basis of many of these problems, the rate of corrosive attack on insulator and conductor hardware depends not only on atmospheric conditions and the kind of material, but also on the electrostatic overstress which may occur at critical points. Regular preventive maintenance, such as the coatings used on steel towers or grounded hardware, is difficult to apply to the energized hardware.

CONDITIONS AFFECTING CORROSION

Atmospheric conditions vary widely and are of primary importance in determining the nature of the corrosion. Two major factors are an excess of oxygen at the metal surface and moisture to form an electrolyte. Action will be accelerated by the presence of air-borne impurities, particularly oxides of sulphur and salts. Dust may serve as a blanket on which moisture may collect. Light rain or mist as a source of moisture will promote corrosion, but frequent heavy rains may wash away contamination and decrease the rate of corrosion, especially for exposed hardware.

The initially formed corrosion products also influence the nature of the attack. Tightly adherent compounds serve as a retardant to further corrosion, but loose and flaky material tends to harbour moisture and to expose new metal surfaces.

When the surfaces of the insulators are covered with damp contamination, leakage currents will flow through this electrolyte. At certain high surface-resistance areas, e.g., at the pinhole of suspension insulators, sufficient voltage may develop to cause temporary air breakdown. This discharge may occur at any insulator of a suspension string if there is enough voltage drop. The ozone formed by the electrical discharge will accelerate the pin corrosion.

PRODUCTS OF CORROSION

Typical ferrous metals used for insulator and conductor hardware are carbon steel, low-alloy steel, and malleable iron. Normally, these parts are hot-dip-galvanized and in a damp atmosphere they quickly develop a surface film of white zinc oxide, which changes to basic zinc carbonate. In mild atmospheres this acts as an insoluble seal and often checks further corrosion for many years. In more corrosive atmospheres the zinc carbonate film is less resistant and the decomposition of zinc and zinc-iron alloy continues. As this attack progresses, the corrosion product assumes more of a red-brown colour because of the presence of more iron in the alloy layers below the original surface. Since zinc is anodic to iron, bare areas of iron or steel up to $\frac{1}{8}$ in. in diameter will be protected. Beyond this stage, corrosion of the base metal will proceed at the same rate as ungalvanized iron or steel.

Ferrous metals in reasonably clean but damp atmospheres form films of hydrated iron oxide which may develop either soft red oxide or hard, dark magnetic iron oxide. Where contaminating salts or fumes are present, the end products are the same but the rate of corrosion is accelerated.

Brass and bronze alloys are specified for critical parts like cotter pins, and for insulator and conductor hardware when corrosion-resisting, non-magnetic, or current-carrying characteristics are especially useful. Corrosion products on this hardware, like zinc, are self-sealing in mild atmospheres. The film again is in the form of oxides and basic carbonates. In more corrosive atmospheres, the film may be dissolved and replaced in a slow but progressive fashion. There is no abrupt change in corrosion rate, as with a galvanized coating over a ferrous base. The corrosion products are soft and do not build up hard radial struts.

Aluminium alloys are specified for suspension and strain clamps used with aluminium conductors, and the non-magnetic, corrosion-resisting nature of the material has been beneficial. These alloys immediately form an almost impervious oxide layer which discourages further corrosion.

VARIABLES OF CORROSION ATTACK

Although metals of similar composition may have what seem to be identical exposures, wide variations in rates of corrosion may result. In some instances these differences can be accounted for by peculiar sheltering circumstances. Thus, it has been observed that in an industrial atmosphere, inclined metal specimens lost 60% of the total weight loss on the groundward side.[1] The skyward surfaces of the specimens, which had the advantage of regular rinsing and drying, lost only 40%. Similarly, it has been observed that the top cap of a suspension in-

sulator string often appears to corrode at a slower rate than the more protected hardware. Hard rains may tend to clean the top cap, but spray rebound may dampen the intermediate caps and pins and foster attack. Variation of corrosion rate sometimes may be attributed to external protection, i.e., poles or structures may shield insulators or hardware from water spray or contamination.

For some cases, changes in location and elevation make a distinct difference. In a seacoast location it was shown by Copson[2] that the corrosiveness of the atmosphere increased with a greater amount of fog and with a wind direction bringing in industrial contamination. High-voltage transmission lines operating in an industrial valley may be subjected to extreme corrosive attack, while the tower just out of the valley may be practically free from attack.

Corrosion of a metal part will vary with the concentration and kind of pollution, degree of rainfall, wind direction and velocity, amount of voltage stress, and other atmospheric conditions such as humidity and temperature. Field tests with energized specimens are necessary to determine how a material will react to a given exposure.

Types of Insulator and Conductor Hardware Corrosion

Examination of corroded metal parts from many kinds of exposures suggests that corrosion may be classified into the following general types :—

Type A : Loss of Section of Exposed Metal

This most common class usually occurs in a contaminated, acid atmosphere, often with frequent rainfall. The general corrosion on the exposed metal surfaces is typical of the atmospheric attack in many industrialized districts. Both insulator and conductor hardware are vulnerable. Ferrous metals which have been hot-dip-galvanized usually exhibit initially a somewhat uniform corrosion of the zinc coating. At surface areas where moisture may be harboured or where electrostatic overstress may be present, corrosion will be accelerated. For suspension insulators, the ball-socket or clevis-tongue connections may be frozen by the corrosion products. The pin shank loses section, especially near the cement line and, in time, so much metal may be lost that the mechanical strength is reduced to a critical value.

Type B : Corrosion of Insulator Pins Extending into the Assembly

For insulator assemblies subjected to certain factors of exposure and voltage stress, the attack on exposed metal described as type *A* will not halt at assembly joints but will continue on metal surfaces within the insulators. The necessary combination of conditions which includes contaminated atmospheres, sheltered insulator locations, frequent periods of dampness, and electrostatic stress has occurred at relatively few locations. The attack develops hard radial struts of iron oxide at the steel insulator pin. In time, these struts extend into the pinhole, exert a bursting pressure, and, as a result, cause radial cracks in the insulator porcelain.

Type C : Corrosion of Insulator Pins within the Assembly

In prolonged and recurring damp atmospheres, insulator surface contamination and electrostatic overstress may lead to radially cracked suspension insulators, with little evidence of external corrosion.

That the insulators must be energized for this type of attack has been demonstrated by the corrosion and cracking of units under voltage, while duplicate insulators, not energized but hung on the same tower, showed no evidence of attack. The ozone formed by the localized electrical discharges is far more active chemically than the normal oxygen in air and accelerates corrosion by what are termed oxygen-concentration cells. When a film of liquid in contact with a metal surface is shielded so that a portion does not have free access to the air, the shielded portion which is low in oxygen becomes anodic, and the corrosion occurs in pits. This has been found at the portion of the suspension insulator pin buried in the Portland cement of the pinhole. Corrosion products such as iron oxide increase the effectiveness of the shield, and the attack proceeds to build up more iron oxide from the centre of the pit. This iron oxide is harder than mild steel and occupies over 50% more volume than the original metal. When confined in the pinhole between the pin and cement, a surprisingly small amount of rusting causes bursting stresses.

Type D : Stress Corrosion

Certain alloys are vulnerable to an intergranular or sometimes a transcrystalline attack when subjected to an unfavourable combination of tensile stress and corrosion. The choice of alloy is vital, especially in the application of aluminium or brasses in corrosive atmospheres.

Type E : Galvanic Corrosion

When dissimilar metals in electrical contact are in an electrolyte, corrosion of the less noble metal occurs in excess of the normal rate expected in that electrolyte, and the more noble metal is protected. Although the position of a metal in the galvanic series is indicative of this tendency, many other factors are involved, including the nature of the electrolyte, the presence of an oxidizing agent, and the relative size of the electrode areas. If the contact of the dissimilar metals is in the electrolyte, severe corrosion usually occurs there.

Type F : Insulating Corrosion Films

The initial corrosion of aluminium or galvanized ferrous hardware surfaces develops a thin film of oxides or carbonates of the metal, together with some soluble salts, depending on the nature of the atmosphere. These films, when dry, have high electrical resistance and in time may develop sufficiently to affect transmission-line performance.

An example is the experience in certain areas with non-heat-treated J-bolt suspension clamps. After a period of service, the J-bolts may relax enough to permit the growth of a corrosion film between the conductor and clamp. The current of power arcs which terminate at the line horn or fittings must pass from the suspension clamp to the conductor through this corrosion film. This causes heating, and burning of the conductor strands may take place. The use of suspension clamps with U-bolts will help to maintain proper pressure on the conductor and prevent this problem.

For lightly loaded suspension insulator strings, a high-resistance film of corrosion may develop at the contact surface of the connecting hardware. Eventually, enough voltage may occur across the film to cause a localized electrical breakdown through the film or adjacent air. This may generate radio or television interference, especially in so-called fringe reception areas. Factors affecting this phenomenon include atmospheric corrosion, time, and the load on the insulator string. Experience has indicated that a few hundred pounds of tensile load is

sufficient to maintain proper contact. Therefore, a limited number of suspension insulators is vulnerable to this type of attack, even in corrosive atmospheres.

Methods of Controlling the Effects of Corrosion

For convenience, methods of controlling the effects of corrosion may be divided into several types, i.e., design factors, coatings, minor and major changes in the composition of the base metal, and application and maintenance factors.

Design Factors :—

Insulator and conductor hardware is used in connection with wet-process porcelain assemblies having certain ultimate strengths. To provide a safety margin for possible loss of strength caused by reduction of section, these metal parts are usually designed to a strength level greater than that of the porcelain, with little economic penalty. A limiting factor in suspension insulator applications is the ball-end used with the standard ball-socket connection. With heat-treated or cold-drawn carbon steel the standard $\frac{3}{4}$-in. shank diameter of this part may be rated at about 27,000 to 30,000 lb ultimate strength. The new American standards for the 25,000-lb rated mechanical and electrical strength suspension insulator have modified this ball-socket connection by specifying an enlarged diameter ball shank of $\frac{13}{32}$ in. This provides not only a better allowance for corrosion attack, but also greater vibration endurance strength.

For suspension insulators subjected to type-*A* or type-*B* corrosion, the greatest loss of metal usually is from the pin near the cement line, and the use of an enlarged pin shoulder is of undoubted value in prolonging service life.

The voltage stress at critical hardware points may be reduced by the use of correct contours and increased radii. For fog-type suspension insulators, which are often subjected to extreme surface contamination and appreciable leakage currents, a metallic coating on the porcelain surface at the pinhole helps to remove possible voltage overstress from the critical pin section.

Cracks, crevices, or pockets which might harbour moisture are eliminated in carefully designed hardware parts. Drainage facilities should be provided, as required.

Coatings :—

Because of the relatively small size and irregular contours of the ferrous parts of insulator or conductor hardware, hot dipping generally is more practicable than either metallized spray coatings or electroplating. Hot-dip galvanizing has had an excellent record of protecting ferrous parts since the early history of high-voltage insulators. The sacrificial zinc coating, properly alloyed to the iron, meets the mechanical requirements of ductility and continues to protect the base metal, even if small areas are not covered. Extensive atmospheric exposure tests[3] have shown that corrosion is unlikely to occur at bare areas of malleable iron or mild steel surrounded by hot-dip-galvanized coatings when such areas do not exceed the equivalent of a circle $\frac{1}{8}$ in. in diameter.

Hot-dip aluminium coating methods have been developed but the technical problems are difficult. The aluminium-bath temperature is considerably higher than that of the zinc bath. Exposure tests in industrial atmospheres have shown that ferrous materials uniformly coated with aluminium by hot dipping have excellent corrosion-resisting properties. A recent American Society for Testing Materials report indicates that hot-dip aluminium coatings on various ferrous metals are equa or superior to hot-dip-galvanized coatings for atmospheric corrosion protection. It has been found, however, that hardware coated with aluminium will develop a high-resistance joint at connections earlier than will galvanized hardware. Aluminium coatings therefore may not meet service demands when type-*F* corrosion film problems are involved.

Non-sacrificial coatings like tin or nickel are not practicable for protecting insulator or conductor hardware. To be effective these coatings must be free from pores. At breaks in the surface the electrolytic action accelerates the corrosion of the ferrous base metal. For the type-*F* insulating film, however, the use of nickel coatings over connecting hardware has indicated some promise because of improved conducting properties.

Many varieties of paints, lacquers, resins, plastics, and chemical reaction films have been tried on both galvanized and plain hardware to isolate the metal from the atmosphere. Recommendation can be given for none, since the life of the coatings is markedly less than the expectancy for the galvanized surface.

Vitreous enamel surfaces have the practical problems of chippage and weakness to mechanical loadings. Since this type of coating is an electrical insulator, contact problems described for type-*F* corrosion also must be solved.

Greases with rust inhibitors have been used for specialized applications and the most effective appears to be one with metal-wetting agents and selected inhibitors in a petroleum base.

Minor and Major Changes in the Composition of the Base Metal :—

Malleable iron generally resists atmospheric corrosion more effectively than carbon steels. Tests have shown a marked difference in corrosion rates[4]. When the protective coating of hot-dip galvanizing is gone, malleable iron corrodes noticeably less than steel parts used with the same fitting. A comparison of the steel pins and malleable iron caps used with suspension insulators also demonstrates the more favourable experience with malleable iron.

For suspension insulators with steel pins and malleable iron caps exposed to corrosive attack, the limiting part usually is the steel pin. For a design balanced in resistance to corrosion, the pin should equal the performance of the malleable iron. Because of strength and endurance requirements of suspension ball pins, malleable iron pins generally cannot be used.

Low-alloy structural steels, containing small amounts of elements such as phosphorus, copper, nickel, chromium, and silicon, have been produced to meet certain conditions of atmospheric exposure. Records show that some of them have worked fairly well in air but no better than ordinary steel when exposed to moist conditions with salts or acids. The protection developed by such additions is dependent upon a finely textured, adherent, dark-coloured rust film of mixed oxides formed and maintained only in relatively dry exposures.

(*Concluded on page 374*)

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RUSSIA

Deep Drawing of Sheet Metal by Friction Forces

By N. A. MASLENNIKOV. (From *Vestnik Mashinostroyeniya*, No. 5, May 1956, pp. 59–63, 6 illustrations.)

THE main shortcoming of existing methods of deep drawing thin metal sheet is the fact that many operations are required, involving a large number of dies and intermediate heat treatments. The reason for the multiplicity of these operations is that the system of forces effective in conventional deep drawing leads to the formation in the component of a dangerous cross-section, which is found in the transition zone where the radius of the drawing punch blends into its cylindrical part. The excessive straining of the metal in this cross-section is caused mainly by tensile stresses which are unfavourable from the point of view of breaking strength, so that the possibility of increasing the reduction in any one operation is limited.

To eliminate these unfavourable conditions of metal deformation, the author has developed and tested a new production process for the deep drawing of sheet metal by means of friction forces. The application of this process permits fewer redrawing operations, as a result of an increase in the maximum reduction possible in a single operation. Thus, for aluminium alloys, it has been found that the limiting drawing ratio has been increased from between 2·0 and 2·5 to between 6·5 and 7·0, while the number of drawing operations has been reduced from eight to one.

The essence of the new process consists of a radical change in the system of forces acting during cupping. In conventional deep-drawing operations the total load is composed of (1) forces necessary for the plastic deformation of the rim of the blank ; (2) forces necessary for bending the material around the radii of the drawing die and drawing punch ; and (3) friction forces between the blank-holder and the blank, and between the blank and the drawing die. The forces necessary for the plastic deformation of the rim of the blank and for bending the material around the punch and the die cannot be varied, since their magnitude depends exclusively on the drawability of the sheet. The only forces which can be modified at will are the friction forces, which depend on controllable factors, i.e., type of lubricant, magnitude of blank-holder pressure, etc.

It is known that external friction forces in ordinary deep drawing are in a direction which is opposite to the flow of metal, thereby opposing its deformation and causing therein tensile stresses. However, if the direction of the friction forces is so changed that it coincides with the direction of metal flow, and if these forces are large enough, then they can become active forces, causing not tensile but compressive stresses in the metal.

Such a change in the system of forces in deep-drawing operations, by reversing the friction forces in the plane between the blank-holder and the blank, is achieved by inserting a suitable flexible friction element under the blank. Experiments have shown that suitable materials for this purpose are rubber, elastomeric plastics, and some metals. In the new deep-drawing method, using a flexible rubber friction element, the reversal of the action of friction forces can be achieved with a special drawing tool, as shown in Fig. 1. At the bottom of the die body (1) is located a rubber ring (2), on which is mounted the blank (3), covered by the die (4) and the sleeve (5). The operating pressure P is transmitted through the sleeve, the die, and the blank to the rubber. Under compression, the rubber moves in the direction of least resistance, i.e., inwards into the die hole, and friction forces draw the rim of the blank in the same direction. Assuming that the friction forces are sufficiently large, by virtue of a certain specific pressure and friction coefficient between the rubber and the blank, the drawing operation will actually be performed by friction. When the load is removed, the rubber is released, the die returns to its initial position, and the process is then repeated.

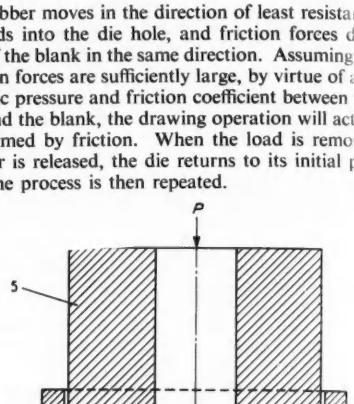

Fig. 1. Detail of tool used for deep drawing by friction.

The state of stress of the blank in this process is much more favourable, and, instead of radial tensile stresses in the material, compressive stresses are produced. The existence of such compressive stresses has been confirmed by measuring the section of a cup produced by this method of punchless drawing, in which the thickness values found showed an increase, instead of the customary reduction, in the dangerous zone of the bend. Experiments have also demonstrated that a flexible friction element of rubber can develop in the plane between the die and the blank friction forces which are large enough for cupping the blank into the die hole without the use of a punch. Moreover, this flexible element fully replaces the action of the blank-holder in preventing wrinkling of the rim of the blank.

Tests on various types of rubber have established that, when compressed in a closed die, the rubber experiences a stressed state of a type which increases its resistance, thereby permitting the application of a relatively high specific pressure during the drawing process. Depending on the type of rubber used, the net friction coefficient, i.e., the difference between the friction coefficients of the rubber against the blank, and the blank against the die, fluctuates between 0·2 and 0·3. Among the many kinds of rubber used in industry, the most suitable for drawing by friction are those which produce the largest active friction forces, which are subject to the smallest residual deformations, which possess high wear resistance, and which resist disintegration, even at relatively high compressive stresses. Tests on the disintegration of rubber rings, 4·9 mm in thickness, and with outside and inside diameters of 80 and 50 mm respectively, showed failure in a closed die body as follows :— Soft rubber suffered a funnel-shaped residual deformation at a pressure of 45 tons ; rubber of medium hardness failed along the hole face at a pressure of 55 tons ; and hard rubber showed no signs of failure, even at a pressure of 100 tons. Consequently, insofar as its resistance is concerned, as

well as its friction properties, hard rubber has proved to be the most suitable.

The conditions of this friction-drawing process demand that the rubber ring should deform evenly throughout its entire thickness, and this is ensured primarily by the choice of an optimum thickness of the ring. Tests have shown this thickness to lie between 5 and 7 mm.

The correct choice of the inside diameter of the rubber ring also has an important significance in friction drawing, as not only the full utilization of the friction forces but also the quality of the component produced will depend on the inside diameter. The diameter of the rubber ring should be so chosen that, during its deformation, it acts on the entire surface of the rim of the blank, including the surface of the drawing edge of the die ; at the same time, however, it must not press against the bottom of the cup during the latter's formation, or tearing may result. Assuming the volume of the rubber to be constant before and after deformation, the following equation for determining the optimum inside diameter d_p of the rubber ring has been developed :—

$$d_p = D^2\delta - d^3/3h_o \quad .. \quad .. \quad .. \quad (1)$$

where d is the diameter of the drawing hole in the die, D is the internal diameter of the die body or the external diameter of the rubber ring, and $\delta = (h_o - h)/h_o =$ the relative compression, h_o and h being the respective thicknesses of the rubber before and after compression.

Of great significance is the correct choice of lubricant, the object of which is to reduce the friction between the rubber and the die body and to create conditions of even deformation of the rubber layers across the thickness of the ring. If, for instance, a lubricant of low viscosity is applied, the rate of deformation of the lower layers of the rubber will increase sharply, compared with the rate of deformation of the upper layers rubbing against the blank, causing a high degree of squeezing and even tearing of the lower layers. On the other hand, if the body of the die is not lubricated at all, the friction forces at the upper and lower surfaces of the rubber ring will be so great that the ring will be squeezed out in the middle until it shreds.

Experiments have determined the optimum formulations of lubricants for ensuring maximum friction forces and the most favourable conditions for an increase in the strength of the rubber. The lubricants finally selected consisted of 70% colophony and 30% castor oil for the contact surface between the rubber and the bottom of the die body, 50% colophony and 50% castor oil for the contact surface between the blank and the die face, and pure colophony powder for the contact surface between the rubber and the blank.

One of the most important production factors in deep drawing by friction forces is the number of strokes necessary for obtaining the required shape of the component. Tests have shown that, with an increase in the initial diameter of the blank, the number of strokes or compressions of the rubber ring required to accomplish the drawing operation increases. With a larger press load P for blanks of the same diameter and of the same material, a lower number of strokes is required. Depending on the degree of slip between the rubber and the blank during each working stroke of the press, a definite deformation of the rim of the blank takes place, and the rim contracts. The decrease in the diameter of the rim occurs mainly in the first few strokes, and then, as strain-hardening of the material progresses, the deformation gradually diminishes and finally ceases.

An analysis of test results has made it possible to express, with an accuracy which is sufficient for practical applications, the relation between the redrawing ratio K (i.e., the drawing ratio for any one compression) of the drawn blank and the number n of compressions of the rubber (provided that this number is less than 15) by means of the following empirical equation :—

$$K = K_o - bPn^m e^{cn/P} \quad .. \quad .. \quad .. \quad (2)$$

where K_o is the initial drawing ratio, P is the pressure [tons], and b, c, and m are constants characterizing the properties of the rubber. Thus, for example, in the case of hard rubber, $b = 0{\cdot}0162$, $c = -1{\cdot}645$, and $m = 0{\cdot}84$.

It is possible to write eq. (2) in a form which is convenient for the determination of the minimum number of compressions necessary to ensure full deformation of the component, i.e., the attainment of a redrawing ratio $K = 1$, starting from the initial value K_o. The minimum number of compressions n is

$$n = -mtP/c \quad .. \quad .. \quad (3)$$

where t is a variable depending on the pressure P for the same type of rubber, or alternatively on the properties of the rubber at a fixed pressure P.

This variable t can be obtained from the expression

$$t = \frac{-(\log_e E - 1) \pm \sqrt{(\log_e E - 1)^2 - 4(\log_e E + 2)}}{2}$$

where $E = -\frac{c}{mP}\left[\frac{K_o - 1}{bP}\right]^{1/m} \quad (4)$

From eqs. (3) and (4) it follows that the number of compressions n depends not only on the pressure P but also on the properties of the rubber used in the deep-drawing operation.

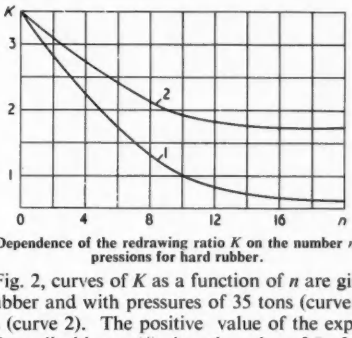

Fig. 2. **Dependence of the redrawing ratio K on the number n of compressions for hard rubber.**

In Fig. 2, curves of K as a function of n are given for hard rubber and with pressures of 35 tons (curve 1) and 30 tons (curve 2). The positive value of the expression under the radical in eq. (4) gives the value of P of 35 tons corresponding to curve 1, and the negative value the 30 tons corresponding to curve 2. The first curve intersects the horizontal $K = 1$ at $n = 10$. Hence, the blank (in this case, of aluminium alloy) can be drawn in 10 strokes. The second curve, however, does not intersect this horizontal line ; in other words, the blank cannot be drawn at all with a pressure of 30 tons.

In Fig. 3 it can be seen that softer grades of rubber yield curves which are situated above the horizontal line $K = 1$, irrespective of the pressure P. These curves, therefore, show that the particular blank cannot be formed by means of these softer grades of rubber.

The specific pressure q exerted on the rubber and required for drawing by friction is determined from

$$q = \theta s/\mu r \quad .. \quad .. \quad .. \quad (5)$$

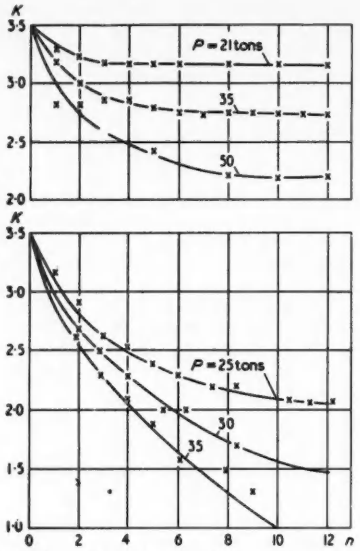

Fig. 3. **Dependence of the redrawing ratio K on the number n of compressions at $K_o = 3{\cdot}5$ for two grades of softer rubber, with different values of P.**

where r is the radius of the drawing hole of the die and s the thickness of the drawn material. The highest value of θ (drawing in a single stroke) can be found from the expression

$$\theta = 1{\cdot}2\sigma_b\,\varepsilon^{\alpha}\,(\log_e K_o)^{\alpha}/\alpha^{\alpha} \quad .. \quad .. \quad (6)$$

where α is the actual elongation of the metal at the instant of necking of a specimen undergoing a tensile test, and σ_b is the yield strength.

The accuracy of the equations obtained was verified by sample calculations and by a large number of friction-drawing tests on blanks of aluminium and aluminium-alloy sheet, with diameters between 40 and 105 mm and thicknesses between 0·5 and 1·5 mm, the drawn components having diameters of 15, 18, 20, 22, 30, and 35 mm. Friction drawing of steel was also attempted. Although these tests have confirmed the theoretical calculations, they establish that a rubber of improved properties is required.

The upper limit of the drawing ratio K_o is not fixed by the mechanism of friction drawing but by the strain-hardening of the drawn material. With very high K_o-values, considerable deformations arise which cause strain-hardening, preventing further plastic deformation and leading to possible failure.

The diameter of the finished component is determined by the physical properties of the flexible friction element used. Under production conditions, the rubber ring should not be loaded beyond 6 or 7 kg/mm^2.

The physical properties of the flexible element affect not only the lower but also the upper limit of the ratio r/s. With an increase in the hole radius of the component, and at a definite value of θ, depending only on K_o and the drawability of the material, the required specific pressure on the rubber decreases and may become so low that the degree of compression of the rubber may be insufficient to produce an appreciable flow in the direction of the drawing hole of the die, in which case a very large number of strokes will be required to complete the drawing operation. On the other hand, if components with a large radius are drawn at too high a pressure, an unnecessarily large press capacity results.

The shape and quality of finished components produced by this system of punchless deep drawing will be adequate if the quality of the rubber used and the dimensions of the rubber ring, as well as the pressure, have been properly chosen. However, the non-uniformity of commercial rubber and its local softness may lead to a slight conicity in components. Also, in a metal sheet with a thickness less than 0·55 mm, slight wrinkling may appear at the surface. To avoid these shortcomings, the components merely require one additional calibrating operation with a conventional deep-drawing tool. Alternatively,

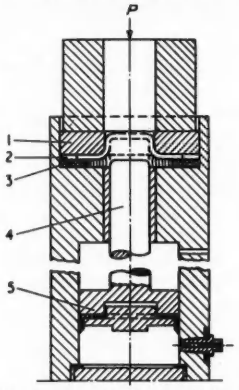

Fig. 4. **Friction-drawing tool with the addition of a punch.**

the friction-drawing method can be supplemented by the additional action of a punch, ensuring a high quality of components, both with and without flanges. Fig. 4 shows the cross-section of the tool with the addition of a punch. The pressure P is transmitted through the die (1) and blank (2) to the rubber ring (3), drawing the blank by friction forces into the die hole. At the same time, a punch (4), operated by an oil- or air-actuated piston (5), advances against the blank at a constant pressure, and also draws the metal into the die.

The introduction of a punch into the friction-drawing method permits not only an improvement in the quality of the finished components but adds a load which facilitates the action of the flexible friction element. The presence of the punch, however, does not lead to modifications in the type of rubber or its thickness, or in the quality of the lubricant used. The only difference introduced by the inclusion of the punch is in the diameter of the hole, which must be such that, even in its extreme position, the rubber, though touching the punch, does not press against it ; otherwise, the friction forces will be reduced. If, however, the diameter of the rubber ring is larger than the optimum diameter determined, this will cause the formation of wrinkles along the radius of the drawing edge of the die.

The equation for the determination of the diameter d_p of the hole in the rubber ring in a closed die with the addition of a punch is

$$d_p = \sqrt{D^2\delta + d_n^2\,(1 - \delta)} \quad .. \quad .. \quad (7)$$

where d_n is the punch diameter.

In drawing by friction forces with the addition of a punch, the magnitude of the clearance between the punch and the die is of definite importance. This clearance must be several times larger than that chosen for conventional deep-drawing operations.

The Use of Open-Cycle Gas Turbines with Blast-Furnaces

By H. BAUMANN. (From *The Brown Boveri Review*, Vol. 43, No. 3/4, March/April 1956, pp. 79–91, 19 illustrations.)

This article discusses a suggestion involving the improved efficiency of blast generation in steelworks, by employing the exhaust gases of an open-cycle gas-turbine plant as combustion air for the air heater and for preheating blast-furnace gas. In addition, an investigation is made into the influence on flame temperature of the various methods of air-heater operation, together with equations for calculating exhaust-gas requirements and the economy in blast-furnace gas achieved by utilizing the exhaust gases in the air heaters.

THE increasing utilization of gas turbines in steelworks can be attributed to their simplicity, their modest cooling-water requirements, their high thermal efficiency, even at low outputs, and the possibility of burning gaseous and liquid fuels, singly or simultaneously.

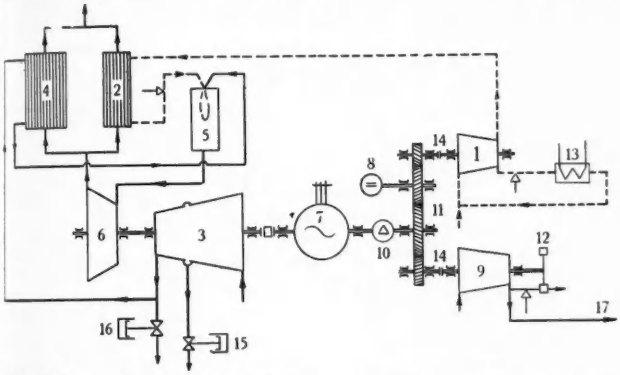

Fig. 1. Diagrammatic arrangement of a gas-turbine plant fired with blast-furnace gas and used for driving a generator and a blast compressor.
(1) Blast-gas compressor.
(2) Blast-gas preheater.
(3) Air compressor.
(4) Air preheater.
(5) Combustion chamber.
(6) Gas turbine.
(7) Generator.
(8) Exciter.
(9) Blast compressor.
(10) Starting motor.
(11) Gearing.
(12) Expansion turbine.
(13) Blast-gas cooler.
(14) Clutch.
(15) Extraction point for furnace blast.
(16) Extraction point for converter blast.
(17) Furnace blast.

Fig. 1 shows diagrammatically the layout of a single-shaft, open-cycle gas-turbine set, fired with blast-furnace gas, and intended for the production of electrical energy. This cycle is particularly interesting for steelworks because, owing to the absence of an intermediate cooler for air compression, only small quantities of cooling water are required ; only for the lubricating-oil and generator cooler is it necessary to provide small quantities of cooling water, generally, however, not in excess of 0·015 m³/kWh. Apart from driving a generator, this gas turbine can also be utilized for driving directly a blast-furnace or a converter compressor (Fig. 1). Extraction at the combustion-air compressor of the gas-turbine plant offers interesting possibilities, a number of which have already been realized in practice.[1] The combined production of electrical energy and blast offers a further possibility ; by disconnecting, by means of a clutch, the generator from the gas-turbine set, the latter can be employed for driving the blast compressor, so that an extremely reliable blast-supply arrangement is achieved.

In addition to the electrical requirements of metallurgical works, there is a heavy demand for blast in the furnace and the converter. The blast-gas turbine fulfils these needs in an ideal manner and is able to convert directly the energy of the blast-furnace gases to blast energy. Fig. 2 shows the circuit which is visualized. A conventional gas-turbine plant drives an air compressor, either directly or by way of gearing. By eliminating the generator from the circuit, the speed of the turbine is adaptable to the blast requirements of the furnace with respect to volume and pressure. The compactness of an installation of this type enables such blast-gas turbines to be installed in the immediate vicinity of the blast-furnace.

It is customary in most steelworks to compress and heat the blast in two separate pieces of equipment, each of which burns the blast-furnace gas supplied to it and has, according to its task, unavoidable exhaust-gas losses. The aim here is to unite thermally these two duties, so as to reduce the total gas consumption to a minimum. Fig. 3 illustrates a suggestion[2] for combining with blast heating a Velox boiler and steam turbine for the production of blast, while Fig. 4 illustrates a scheme for combining blast heating with a gas-turbine plant[3] for the same purpose. A feature common to both solutions is that the turbine and the air heater share the same combustion chamber, so that the exhaust-gas losses of the air heater are obviated. With particular reference to Fig. 4, it is possible, without having to add cold air, to cool the working gases from the flame temperature down to a level permissible for the gas turbine ; this cooling, which is essential in gas-turbine practice, is achieved around the heat-exchange surfaces of the air heater.

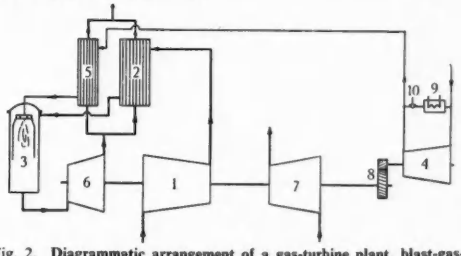

Fig. 2. Diagrammatic arrangement of a gas-turbine plant, blast-gas-fired, for producing blast.
(1) Combustion-air compressor ; (2) air preheater ; (3) combustion chamber ; (4) blast-gas compressor ; (5) blast-gas preheater ; (6) gas turbine ; (7) blast blower ; (8) gearing ; (9) blast-gas cooler ; (10) blast-gas bypass regulating-valve.

With these circuits the heat consumption, compared with conventional arrangements having separate blowers and blast heaters, is reduced to about 80%. The question which remains to be cleared up is why these interesting proposals have been advanced, considering that, to a

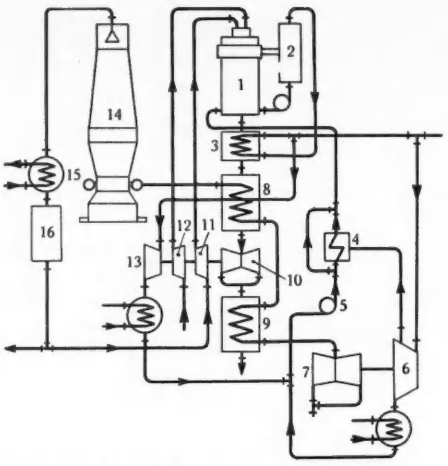

Fig. 3. **Blast-furnace turbo-compressor and Velox blast-heating installation.**
(1) Steam generator ; (2) water separator ; (3) superheater ; (4) feedwater heater ; (5) boiler-feed pump ; (6) steam turbine ; (7) furnace-blast compressor ; (8) air heater II ; (9) air heater I ; (10) gas turbine ; (11) gas compressor for boiler ; (12) air compressor for boiler ; (13) steam turbine ; (14) blast-furnace ; (15) gas cooler ; (16) gas purifier.

certain extent, they have been in existence for twenty years without being realized in practice. Probably, the main reason is that, in order to achieve this improvement, it is essential to visualize a complete and inseparable unification of blast production and blast heating in a *single* circuit. This, however, renders the installation extremely sensitive insofar as the removal of one element from the system jeopardizes the entire blast supply. Further proposals to improve heat consumption will therefore have to take this fact into consideration, and every effort must be made to avoid an inseparable unification of the compressor and the air heater and, as far as possible, to leave these components in their present forms.

In connection with three types of blast-producing installations encountered to-day, i.e., the gas engine, the steam-driven turbo-compressor, and the gas turbine, observation of the corresponding heat-flow diagrams has indicated the form in which the non-available energy, according to the second law of thermodynamics, is given up to the surroundings, and has led to a new suggestion for improving the thermal efficiency of blast-producing equipment.

The gas engine produces blast and gives up to the cooling water and exhaust gases a large proportion of the heat supplied, and this proportion is no longer available to the engine. A well-known and extensively employed method of utilizing these exhaust gases is to divert them through a waste-heat boiler, using the steam produced to drive a turbine, which provides additional work. This series-connected steam process brings an additional element into the gas-engine cycle and in any case does not constitute a simplification ; its presence, however, is economically justified in many cases. On the other hand, it would not be possible to utilize the exhaust gases from a gas engine in a series-connected combustion process, as encountered, for example, in an air heater, because these gases have only a very small amount of excess air and would hardly conduce to stable combustion. Moreover, bearing in mind the large amount of heat conveyed away by the cooling water of the engine, the flame temperature would be quite inadequate.

In the steam-driven turbo-compressor, the non-available energy (greatly depreciated as a result of the low temperature) is given up to the surroundings by way of a condenser. Within the output range encountered in present-day steelworks practice, this cycle is generally so developed and complete that any further improvements can hardly be expected.

In the gas turbine, the greater part of the non-available energy—as in the case of the gas engine—is conducted away via the flue. Thus, it would be possible, by connecting in series a waste-heat boiler or another heat consumer, to make use of a part of the exhaust gases. The regenerative air heater, usual in steelworks for preheating the blast, provides a unique opportunity for utilizing the large quantity of sensible heat contained in the exhaust gases of the gas turbine, provided that these still have a useful proportion of oxygen.

In considering the new suggestion regarding the closer thermal connection between the blast-producing gas turbine and the furnace blast heater, whereby no essential alteration is made to either component, Fig. 5 shows diagrammatically the envisaged connection between the gas-turbine plant (1) and the air heater (7). Some of the exhaust gases expelled from the gas-turbine process at (3) are conveyed as combustion air to the blast heater by way of connection (4), while some is passed through the heat exchanger (6) in order to preheat the blast gas of the air heater. It will be shown that the sensible heat of the exhaust gases from the gas turbine is of benefit to the air heater, while the gas turbine is credited with the economic improvement achieved by the saving in fuel in the air heater. It may be said that a mutually beneficial partnership exists between the gas turbine and the blast furnace, i.e., the air heater. If, for any reason, these two partners have to be separated, the operation can be carried out without the gas-turbine performance being impaired in any way ; the air heater, too, under present-day working conditions, can carry out its duty without interruption. This is of decisive importance, and it can be assumed that

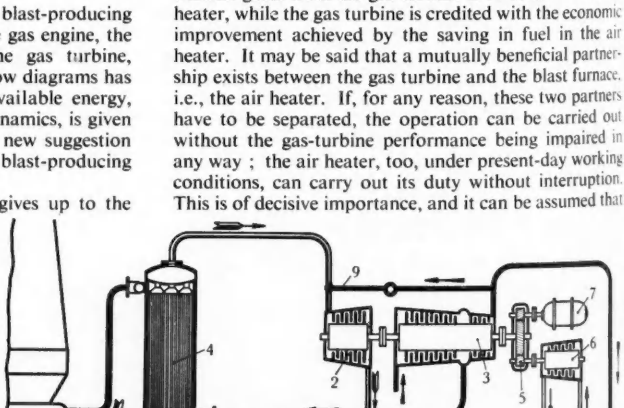

Fig. 4. **Combined gas-turbine installation for generating and heating blast.**
(1) Blast-gas-fired combustion chamber.
(2) Gas turbine.
(3) Compressor for combustion air and blast.
(4) Pressure-charged air heater.
(5) Gearing.
(6) Blast-gas blower.
(7) Starting motor.
(8) Air preheater.
(9) Connection for controlling the temperature ahead of the gas turbine.

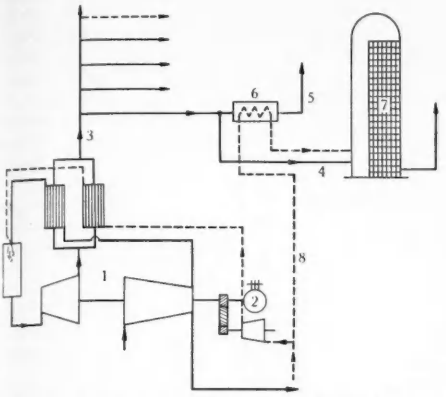

Fig. 5. **Diagrammatic arrangement of a plant for utilizing the exhaust gases from a gas turbine for heating blast-furnace air heaters.**
(1) Gas-turbine plant ; (2) generator ; (3) outlet for the hot exhaust gases from the gas-turbine cycle ; (4) connection to the air heater, conveying exhaust turbine gases to be utilized as combustion air ; (5) exhaust gases for preheating the air-heater blast gas ; (6) blast-gas preheater ; (7) blast heater ; (8) blast-gas supply line.

this method of combination between gas turbine and blast furnace will be more readily accepted and more easily realized than the suggestions made by Noack.[2, 3] In order to appreciate how the exhaust gases from the gas-turbine plant can be employed in the air heater, it must be realized that these gases consist mainly of hot air, slightly impurified by the presence of flue gases. Because, up to the present, it is still necessary to limit the turbine-inlet temperature to between 600 and 700°C, considerably more air has to be delivered to the combustion chamber than is required for the theoretical combustion of the blast gas. This excess air is mixed with hot flame gases at the outlet from the combustion chamber proper, and, as a result, a permissible mixed-gas temperature is obtained for the gas turbine. This explains why the exhaust gases from the turbine still contain from 18 to 19% oxygen, compared with 21% in atmospheric air, and why the exhaust gases from the gas turbine are employed as combustion air in the manner which has long been customary in two-stage gas-turbine installations with reheat.

Flame Temperature in Air Heaters, using Gas-Turbine Exhaust Gases

A major objection to employing as combustion air the exhaust gases from the turbine is that the temperature conditions in the air heater are thereby appreciably altered. It might well be feared that combustion temperatures would rise noticeably, causing the cupola temperature—decisive for the operational safety of the air heater—to be exceeded. It might be argued, however, that solely by virtue of the gas-turbine output the possibility of an inadequate temperature in the blast heater cannot be ruled out, whereby the heating capacity of a given blast-heating system might be reduced. It is now proposed to show that, by correctly controlling the combustion in the air heater, it is easily possible to avoid these two dangers.

Air Heaters Operated with Atmospheric Air :—

Under present-day conditions of air-heater operation, the quantity of heat Q_1 introduced when a volume of blast-furnace gas M_{G_1} is burned in the blast heater can be expressed as

$$Q_1 = (CV_L + i_{G_1} + \lambda_1 Z_1 i_A) M_{G_1}$$

where i_{G_1} is the enthalpy of the blast-furnace gas, i_A is the enthalpy of the air, CV_L is the lower calorific value, λ_1 is the excess-air factor, and Z_1 is the theoretical quantity of air required for complete combustion.

The volume of exhaust gas M resulting from this combustion is

$$M = (1 + \lambda_1 Z_1) M_{G_1}$$

The enthalpy of the flame i_{F_1} is obtained from

$$i_{F_1} = \frac{CV_L + i_{G_1} + \lambda_{1\,1} Z i_A}{1 + \lambda_1 Z_1} \quad .. \quad .. \quad (1)$$

Air Heaters Operated with Exhaust Gases :—

In the case of air heaters operated with exhaust gases, the enthalpy of the flame i_{F_2} can be expressed as

$$i_{F_2} = \frac{CV_L + i_{G_2} + \lambda_2 Z_2 i_{EG}}{1 + \lambda_2 Z_2} \quad .. \quad .. \quad (2)$$

where i_{EG} is the enthalpy of the exhaust gas from the gas turbine, after the air preheater.

The air (or exhaust-gas) requirements Z_2 depend solely upon the excess air in the combustion chamber of the gas turbine, and can be determined from the theoretical ratio of the quantity of turbine exhaust gases Z_2 to the theoretical quantity of air Z_1, required to burn 1 kg of blast gas, this ratio being

$$\frac{Z_2}{Z_1} = \frac{M_{AGT} + M_{GGT}}{M_{AGT} - Z_1 M_{GGT}} \quad .. \quad .. \quad .. \quad (3)$$

where M_{AGT} and M_{GGT} are respectively the quantities of combustion air and blast-furnace gas. In eq. (3), therefore, the numerator refers to the total mass of exhaust gas leaving the gas turbine, while the denominator refers to the pure air left in it.

The excess-air factor of the gas-turbine exhaust gases λ_{GT} is defined as

$$\lambda_{GT} = \frac{M_{AGT}}{Z_1 M_{GGT}}$$

from which, by rearrangement of eq. (3)

$$Z_2 = \frac{\lambda_{GT} Z_1 + 1}{\lambda_{GT} - 1} \quad .. \quad .. \quad .. \quad .. \quad (4)$$

From eqs. (2) and (4) the flame enthalpy i_{F_2} can be obtained as

$$i_{F_2} = \frac{(CV_L + i_{G_2})(\lambda_{GT} - 1) + \lambda_2 i_{EG} (\lambda_{GT} Z_1 + 1)}{\lambda_{GT} - 1 + \lambda_2 (\lambda_{GT} Z_1 + 1)} \quad .. \quad (5)$$

Based on actual numerical values, theoretical flame temperature T, calculated from eqs. (1) and (5), is plotted against theoretical excess-air factor λ in Fig. 6. In this instance, and in all other calculations in this article, it should be pointed out that the convection and radiation losses, and also the dissociation of the gases at high flame temperatures, have not been taken into consideration. Since the influence exerted by these factors is virtually the same for both forms of air-heater operation (i.e., with pure air and gas-turbine exhaust gases) they cannot affect comparative calculations and have, for the sake of simplicity, been ignored. In order to characterize this incompleteness, the enthalpy i_F and the temperature T have been defined as " theoretical " values. From Fig. 6 it will be seen, with the excess-air factor of 1·25 customary to-day in air-heater operation, that a theoretical flame

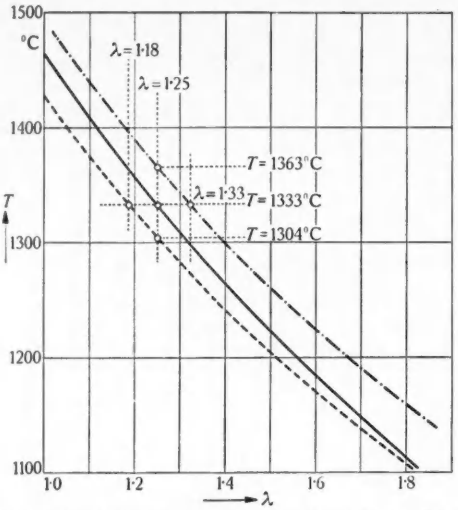

Fig. 6. Theoretical flame temperature T in the air heater, plotted against theoretical excess-air factor λ, with and without turbine exhaust-gas utilization.
Solid curve : Normal air-heater operation.
Dotted curve : Exhaust-gas utilization without preheating of blast gas.
Chain-dotted curve : Exhaust-gas utilization with preheating of blast gas.

temperature of 1333°C obtains. If, now, in place of cold combustion air, exhaust gases are introduced into the air heater from a gas-turbine plant (as in Figs. 1 or 2) operated with a temperature of 750°C ahead of the turbine, the flame temperature drops (with the same amount of excess air) by 29°C to 1304°C. This phenomenon would result in a protraction of the heating-up time or, assuming constant heating-up time, in a drop in blast temperature. However, as the diagram shows, this disadvantage can be completely overcome by reducing the excess-air factor to 1·18. The chain-dotted curve in Fig. 6 shows that, by employing the turbine exhaust gases as combustion air and, at the same time, for preheating the blast gas of the air heater (in accordance with the arrangement illustrated in Fig. 5), the flame temperature is increased by 30°C to 1363°C. In order to obviate the danger of damaging the brickwork, it is customary to keep the cupola temperature of an air heater down to a safe level ; with this type of operation it is therefore better, by increasing the excess-air factor to 1·33, to reduce flame temperature to that value which has proved permissible under present-day conditions.

It should also be mentioned that, in all comparative calculations in this article, the excess-air factor has been adapted to the various methods of operation, so that the flame temperature corresponds to that employed at the present time. In this way all objections concerning overheating of brickwork or inadequate blast heating are eliminated.

Possible Combination of Blast-Gas Turbine and Blast-Furnace, Utilizing Exhaust Gases

In Fig. 7, the blast-gas turbine delivers the blast for the furnace. The exhaust gases are employed as combustion air in the air heater belonging to the blast-furnace, and for preheating the blast gases which are burned in the air heater. The blast-gas turbine and the blast-furnace from a unit. When exhaust gases are employed in the blast heaters of a blast-furnace, there is invariably an excess of the former, so that it is advisable not to rely on the gas turbine for the back-pressures required by the burners in the blast heater and the blast-gas preheater, but to visualize a fan for conveying the necessary volume of exhaust gas. This arrangement is somewhat more expensive, but the energy requirements are smaller; moreover, the blast heaters are able to work quite independently of gas-turbine performance. If, during periods when the gas turbine operates under partial-load conditions, the capacity of the fan is greater than the volume of exhaust gas, the correct balance is restored automatically by the intake of an appropriate quantity of fresh air, so that it is not necessary to adjust any dampers. The foregoing clearly explains the complete independence of one element from the other.

Owing to the fact that the blast gas of the air heater is simultaneously preheated when the exhaust gases are utilized, the greatest possible quantity of exhaust gas can take part in the blast-furnace process, so that thermal efficiency is increased to its peak value. Because exhaust gases are normally available in excess, it is feasible—with the same circuit—to employ these gases from *one* turbine in *several* blast-furnaces, in which case the layout shown in Fig. 7 remains essentially the same.

In the arrangement shown in Fig. 8 the assumption has been made that *one* blast-gas turbine is to be installed in a large steelworks having existing blowers in the from of gas engines or steam-turbine-driven blowers (repre-

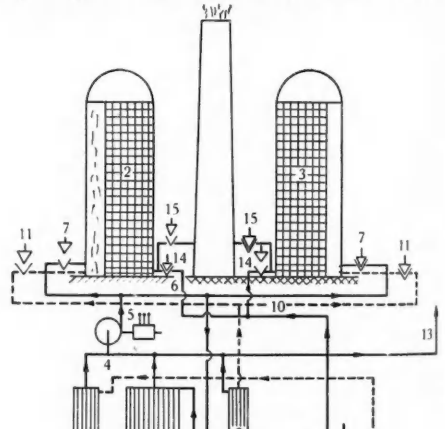

Fig. 7. Diagrammatic arrangement of an installation utilizing the exhaust gases from a blast-gas turbine plant for heating the air heaters of a blast-furnace.
(1) Blast-gas turbine plant ; (2) air heater being heated ; (3) air heater in use ; (4) exhaust-gas extraction point ; (5) exhaust-gas fan ; (6) exhaust-gas distribution pipework ; (7) exhaust-gas inlet valve ; (8) fan handling blast gas ; (9) blast-gas preheater ; (10) blast-gas distribution pipework ; (11) blast-gas inlet valve ; (12) exhaust gases for preheating blast gas ; (13) flue for excess turbine-exhaust gas ; (14) inlet valve for furnace blast ; (15) outlet valve for exhaust gases from air heater.

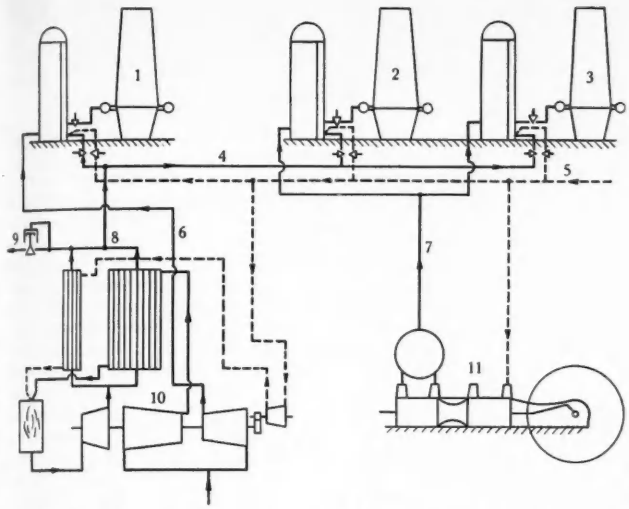

Fig. 8. **Diagrammatic arrangement of an installation utilizing the exhaust gases from a blast-gas turbine plant for heating the air heaters of a number of blast-furnaces blown by gas engines.**
(1) Blast-furnace, blown by a blast-gas turbine.
(2) (3) Blast-furnaces, blown by gas engines or steam-driven turbo-compressors.
(4) Exhaust-gas distribution main.
(5) Existing blast-gas distribution main.
(6) Blast main for blast-furnace (1).
(7) Blast main for blast-furnaces (2) and (3).
(8) Exhaust-gas extraction point.
(9) Back-pressure regulator for exhaust gas.
(10) Blast-gas turbine for blast-furnace (1).
(11) Gas engine for supplying blast to blast-furnaces (2) and (3).

sented in the diagram by the reciprocating compressor (11)). The ample exhaust gases from the gas turbine can be utilized as combustion air in a number of blast-furnace air heaters; the volume is insufficient, however, to heat the associated blast gas as well. When all the exhaust gases are employed, it is possible even to dispense with a fan, the gas turbine itself producing the necessary pressure, naturally not without a certain drop in output. For keeping the air heaters in operation when the gas turbine is out of service, an air-supply fan should be considered for every heater, in accordance with normal practice. Although this arrangement is extremely simple, it is feasible and economical only in those cases where *one* gas turbine with not too high an output is installed in a works employing a number of blast-furnaces.

Saving in Fuel and Exhaust-Gas Requirements, using Turbine Exhaust Gases in the Air Heater

In this section it is proposed to determine the blast-furnace gas quantity theoretically required, with normal air-heater operation and with exhaust-gas utilization, for heating the blast up to the temperature necessary in the blast-furnace. In the following, the saving in blast gas and the exhaust-gas requirements are deduced.

Fuel Consumption with Normal Air-Heater Operation :—

The quantity of heat Q_{B_1} given up by the blast heater during the blast-heating period can be expressed as

$$Q_{B_1} = (i_{B_h} - i_{B_c})\, M_B \qquad .. \quad .. \quad .. \quad (6)$$

where M_B is the blast quantity and i_{B_h} and i_{B_c} the hot and cold enthalpy respectively of the blast.

Under present-day conditions of air-heater operation, the quantity Q of heat stored in the brickwork while the air heater is being heated is

$$Q = [CV_L + i_{G_1} + \lambda_1 Z_1 i_A - (1 + \lambda_1 Z_1)\, i_{f_1}] M_{G_1} \qquad .. \quad (7)$$

where i_{f_1} is the enthalpy in the flue of the air heater and where the expression $(1 + \lambda_1 Z_1)\, i_{f_1} M_{G_1}$ represents the flue loss occurring at the air heater. From eqs. (6) and (7), the quantity of gas M_{G_1} required to heat the blast can be calculated as

$$M_{G_1} = \frac{M_B\,(i_{B_h} - i_{B_c})}{CV_L + i_{G_1} + \lambda_1 Z_1 i_A - (1 + \lambda_1 Z_1) i_{f_1}} \qquad .. \quad (8)$$

Fuel Consumption, using the Exhaust Gases from the Gas Turbine :—

Having regard to the foregoing considerations, the gas consumption M_{G_2} amounts to

$$M_{G_2} = \frac{M_B(i_{B_h} - i_{B_c})}{CV_L + i_{G_2} + \lambda_2 Z_2 i_{EG} - (1 + \lambda_2 Z_2)\, i_{f_2}} \qquad .. \quad (9)$$

With the reservation that flame temperature T for operation with exhaust gases must be the same as that for normal operation, then

$$i_{F_1} = i_{F_2}$$

for λ_2, or with eqs. (1) and (2),

$$\frac{CV_L + i_{G_1} + \lambda_1 Z_1 i_A}{1 + \lambda_1 Z_1} = \frac{CV_L + i_{G_2} + \lambda_2 Z_2 i_{EG}}{1 + \lambda_2 Z_2}$$

so that

$$\lambda_2 = \frac{1}{Z_2}\left(\frac{\lambda_1 Z_1\,(CV_L + i_{G_2} - i_A) + i_{G_2} - i_{G_1}}{CV_L + i_{G_1} - i_{EG} - \lambda_1 Z_1 (i_{EG} - i_A)}\right) \qquad .. \quad (10)$$

In the following, it is no longer required to determine the absolute fuel consumption when employing exhaust gases from the turbine in the blast heater. What is required is the resulting saving compared with normal operation, and this can be expressed as

$$\frac{\Delta M_G}{M_B} = \frac{M_{G_2} - M_{G_1}}{M_B}$$

or, with eqs. (8) and (9),

$$\frac{\Delta M_G}{M_B} = \frac{i_{B_h} - i_{B_c}}{CV_L + i_{G_1} + \lambda_1 Z_1 i_A - (1 + \lambda_1 Z_1)\, i_{f_1}} - \frac{i_{B_h} - i_{B_c}}{CV_L + i_{G_2} + \lambda_2 Z_2 i_{EG} - (1 + \lambda_2 Z_2)\, i_{f_2}}$$

from which, by means of eqs. (1), (2), and (10), the saving in fuel in the air heater when utilizing exhaust gases, compared with normal operation and the same flame temperature, is obtained as

$$\frac{\Delta M_G}{M_B} = (i_{B_h} - i_{B_c}) \times \frac{i_{G_2} - i_{G_1} + \lambda_1 Z_1\,(i_{EG} - i_A)}{[CV_L + i_{G_2} - i_{EG}][CV_L + i_{G_1} + \lambda_1 Z_1 i_A - i_f\,(1 + \lambda_1 Z_1)]} \qquad .. \quad (11)$$

assuming that $i_{f_1} = i_{f_2}$, i.e., that the flue temperature when operating with exhaust gases from the turbine is the same as that obtaining under normal operating conditions. The preheating of the blast gases for the air heater by means of the turbine exhaust gases is taken care of by the blast-gas enthalpies, i_{G_1} in the case of normal operation, and i_{G_2} when exhaust gases are utilized. When the blast gas of the air heater is not preheated $i_{G_2} - i_{G_1} = 0$.

Consumption of Gas-Turbine Exhaust Gases in the Air Heater :—

In order to calculate the possible saving in blast gas when the exhaust gas is utilized, it is necessary to know how much of the latter, from the turbine, is required to heat a definite quantity of blast. By definition, this amounts to

$$M_{EG}/M_B = \lambda_2 Z_2 M_{G_2}/M_B \quad .. \quad .. \quad .. (12)$$

In the following calculation, it is assumed that i_{B_h} and i_{B_c} are the same for all forms of operation, and that $i_{f_1} = i_{f_2}$. By means of eqs. (1), (2), and (10), it is then possible to rearrange eq. (12) so as to determine the quantity of turbine exhaust gas M_{EG} required as combustion air in the air heater for heating the blast quantity M_B, giving

$$\frac{M_{EG}}{M_B} = (i_{B_h} - i_{B_c}) \times \quad .. (13)$$

$$\frac{i_{G_2} - i_{G_1} + \lambda_1 Z_1 (CV_L + i_{G_2} - i_A)}{[CV_L + i_{G_2} - i_{EG}][CV_L + i_{G_1} - i_f + \lambda_1 Z_1 (i_A - i_f)]}$$

The amount of turbine exhaust gas given by eq. (13) is only that part which is required for combustion in the air heater ; eq. (13) is valid, however, according to the values inserted for i_{G_1} and i_{G_2}, with and without preheating the air-heater blast gas.

If it is desired to preheat with turbine exhaust gas the blast gas for heating the air heater (as in Fig. 7), the following can be derived from an intermediate development of eq. (13), when the necessary exhaust-gas quantity is made to equal the quantity of blast gas M_{G_2} to be heated up :

$$M_{EG_{tot}}/M_B = (M_{EG}/M_B) + (M_{G_2}/M_B)$$
$$= (1 + \lambda_1 Z_1)\, M_{G_1}/M_B \quad .. \quad .. \quad .. (14)$$

from which, employing eq. (8), the total quantity of turbine exhaust gas $M_{EG_{tot}}$ required for the combustion and preheating of the blast gas can be derived as

$$\frac{M_{EG_{tot}}}{M_B} = (i_{B_h} - i_{B_c}) \times$$
$$\frac{1 + \lambda_1 Z_1}{CV_L + i_{G_1} + \lambda_1 Z_1 i_A - (1 + \lambda_1 Z_1)\, i_f} \quad .. \quad .. (15)$$

The remarkable feature of this equation is that the required volume of turbine exhaust gas is not related to its temperature. Eqs. (11), (13), and (15) furnish all the data needed for the rapid determination of exhaust-gas requirements for every case of exhaust-gas utilization.

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The Corrosion of Insulator and Conductor Hardware

(*Concluded from page* 365)

For extreme industrial or marine exposures which may cause corrosion described as types *A*, *B*, or *C*, silicon bronze or stainless steel has been used to replace the carbon-steel parts of insulators or conductor hardware. In many instances, these special parts have been used with malleable iron castings, hot-dip-galvanized, with excellent service records in widely differing atmospheres.

For extreme conditions the malleable-iron insulator caps or conductor hardware have been replaced with bronze or stainless-steel parts. These solutions involve marked increases in manufacturing costs and can be justified only where the greater hardware life permits other savings.

Because of the increased use of aluminium conductors and because of their non-magnetic features, aluminium-body suspension and strain clamps have become increasingly popular. As indicated by stress-corrosion studies, the choice of alloy is vital in obtaining good corrosion resistance in a given atmosphere. Parts of carbon steel or malleable iron, hot-dip-galvanized, and stainless steel are used with the aluminium body where strength is required. Service history shows that these materials, reasonably close in the galvanic series, may be used together without corrosion danger.

Connecting-line hardware fittings usually are of standard galvanized ferrous design. In extremely corrosive areas it is often less expensive to replace the fittings and insulators after years of exposure than initially to use more costly stainless-steel hardware.

When made of suitable aluminium alloys, standard suspension hardware connections of the clevis-tongue type will have tensile strengths about 60% of those assigned to the steel design. Aluminium alloys have not been specified for suspension insulator hardware, but greater interest may develop for apparatus insulators, especially when used with aluminium busbars. Insulator designs must be modified for aluminium parts. Not only does aluminium have a reduced strength, but its modulus of elasticity is only about one-third that of steel. The thermal coefficient of expansion of aluminium is over twice that of steel and about four times that of porcelain. This exaggerates the difficulty in designing and manufacturing porcelain-metal assemblies of given strength suitable for applications at widely varying temperatures.

Application and Maintenance Factors :—

Corrosion factors sometimes are a determining consideration in the location of a substation or transmission line. Substations, for example, preferably should be located on the windward, not lee, side of spray ponds. A longer transmission line may require less expensive maintenance if it avoids an area of extreme contamination.

For water-soluble types of contamination, frequent washing will naturally help to reduce the corrosion rate. Where service problems require additional action, coating both the insulator and hardware surfaces with long-life greases will retard corrosion. The hardware surface will be protected, and the grease on the insulator surface will help to prevent the formation of an electrolyte and will reduce leakage-current surges. This is beneficial, as the possibility of electrostatic overstress and the formation of ozone is decreased.

The Embedding of Soft Magnetic Materials in Plastics

By R. Boll. (From *Elektrotechnische Zeitschrift* (*ETZ*), Edition A, Vol. 77, No. 14, July 11, 1956, pp. 483–487, 12 illustrations.)

The fact that the characteristics of magnetic materials can be varied by mechanical stresses has long been known. In general, these variations are more pronounced for materials with a high permeability, i.e., a steep hysteresis loop. Such mechanical stresses can occur when high-grade magnet cores are embedded in synthetic materials, and this article shows how these stresses can be avoided, or alternatively utilized to obtain improved magnetic properties.

The effect of a mechanical load on the magnetization curve depends primarily on the type of magnetic material subjected to such a load. For instance, a tensile stress will flatten the magnetization curve of nickel, whereas it will steepen the curve of nickel-iron containing 68% nickel. When these two materials are put under compression, precisely opposite effects occur, their behaviour being different because the magnetostriction of nickel is "negative", i.e., the orientation of its elementary magnetic regions is made more difficult by tensile loading, whereas orientation is facilitated ("positive" magnetostriction) in the case of the nickel-iron alloy.

It is relatively easy to determine the physical causes for the above materials and loading conditions. However, with soft magnetic alloys, the conditions become considerably more complicated. In general, the alterations of the magnetization curve depend not only on the absolute value of positive or negative magnetostriction but also on internal stress conditions and magnetic crystal anisotropy[1,2].

In practice, soft magnetic materials are nearly always subjected to mechanical stresses, as for instance in winding or assembling laminated cores[3]. As these materials are very sensitive to such stresses, special precautions and very careful handling are required. As a result, practical difficulties arise, making it nearly impossible to utilize fully the properties of high-grade materials. Various processes were therefore tried, in order to strengthen and protect magnetic materials, so as to obtain stable and mechanically insensitive components. Dipping and impregnation methods were first considered, as well as the possibility of embedding the cores in synthetic materials. It has been found, however, that the usual dipping or embedding procedures are not suitable for this application, because they alter magnetic properties considerably.

Factors Causing Mechanical Stresses

When mechanically sensitive magnetic materials are embedded or dipped in plastics, the difficulties arising are due primarily to the shrinkage of the synthetic material while it is setting and also to its comparatively greater changes in length with temperature fluctuations. Other causes are the different moduli of elasticity of plastic and metal and the changes in the dimensions of the magnetic material associated with magnetization.

Owing to these differences in behaviour, mechanical stresses occur in the plastic and hence also in the magnetic material as a result of embedding, dipping, or impregnation. The stresses in the plastic (if it is sufficiently transparent) can be made visible and measured in polarized light[4]. Compressive stresses are caused in the metal and, depending on the ratio of the cross-sectional areas, the stresses in the magnetic material can be a multiple of those in the plastic. Thus, for instance, in partially encased specimens the static stresses were found to be about 40 kg/mm², and it should be remembered that a stress of only 1 kg/mm² is sufficient to cause appreciable changes in magnetic properties.

The shrinkage stresses of the plastic mass or impregnating varnish are not the only factors of importance. When a laminated core is embedded in a synthetic material, the latter tends to prevent changes imposed by magnetization (magnetostrictive changes) and in this way mechanical stresses are generated in the metal.

Influence of Various Types and Quantities of Plastic

The extent to which magnetic properties are altered depends primarily on the shrinkage of the plastic used and on the relative area or volume ratio of the plastic and metal.

As yet, no absolutely shrink-free synthetic material exists. The relative shrinkage ranges from about 0·5% to 5% for those plastics which are nearest to being suitable for casting and dipping applications (e.g., epoxy resins and polyester resins). Shrinkage depends on the setting temperature and the amount of fillers, and can be regarded as constant under certain conditions.

To investigate the dependence of magnetic values on the quantity of synthetic material related to the core volume, determined quantities of the synthetic product were applied on or between the sections of laminated cores. The latter were of a high-permeability nickel-iron alloy (mu-metal) or of 3% silicon-iron with magnetic direction of orientation. The synthetic resin used was Araldite XV. The mu-metal was chosen for the investigation of changes of initial permeability, whereas the silicon-iron served to determine changes in iron losses.

The results obtained show a decreasing initial permeability in the case of mu-metal, and an increase in iron losses in the case of the silicon-iron, with an increase in the proportion of synthetic material. From these results it can also be concluded that strong bonding or impregnation reduces the quality of a laminated silicon-iron texture to that of an ordinary transformer sheet.

From theoretical considerations and experience, it is known that sensitivity to mechanical stresses increases with the permeability value of a material. Accordingly, it can be expected that the impregnation of a high-permeability alloy will be much more difficult than that of an ordinary iron core. To verify this, cores from the complete range of soft magnetic materials available were impregnated with synthetic resin (Araldite XV). The initial permeabilities were between 100 and 100,000, and the proportion of synthetic material used was approximately the same in all cases. The tests confirmed that there was a variation in initial permeability (at 0·015 oersted) for nearly all the materials investigated, and that the variation was more pronounced for materials with high permeability values.

For laminated cores subjected to a dipping process, the proportion of plastic to core volume in most cases is about 5 to 10%. However, when transformers, converters, and other electrical equipment are completely encased, the volume of the plastic is frequently greater than that of the magnetic core, so that the latter sustains particularly high mechanical stresses. Furthermore, as most

plastics, particularly thermoplastics, continue to shrink after setting, sometimes to a considerable extent, it is desirable, when investigating plastics suitable for impregnation, to temper them at 80°C for 24 hr after setting; otherwise, false impressions can easily be obtained regarding their actual suitability.

Reinforcing Laminated Cores without Alteration of Magnetic Values

In view of the deterioration of magnetic properties occurring with the usual embedding processes, it has been necessary to seek other solutions. An obvious suggestion involves the use of protective shells or casings of plastic or metal, and polyvinyl chloride is frequently employed for this purpose, since it is easily machined. However, because of its low thermal resistance (70 to 80°C), it is not always suitable. More recently, glass-fibre materials with a polyester resin as the bonding medium have provided the possibility of producing casings which have a considerably higher thermal strength (e.g., up to 200°C). Other materials, such as nylon and teflon, can also be considered.

The use of protective casings, however, does not provide a truly satisfactory solution. The casings protect the cores but not the windings, and the coil space is less well utilized. Moreover, to make these casings, expensive moulds are required for compression- or injection-moulded parts, and these are economical only in large-scale production. Owing to the wide variety of core sizes and shapes frequently required only in small quantities, the production of casings in many instances is an expensive undertaking. Also, cores enclosed in such casings are not held firmly enough to be truly insensitive to vibrations or changes in position. In magnetic amplifiers, for instance, this can have serious consequences if the electrical compensation of the choke coils is disturbed by some change in position.

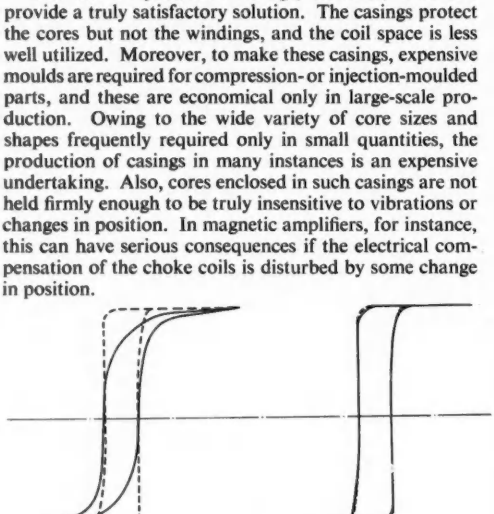

Fig. 1. Influence of the embedding process on the hysteresis of cores of a 50% nickel-iron with a rectangular hysteresis loop, using (a) conventional varnish impregnation and (b) the new method.
Dotted curves : Original condition.
Solid curves : Condition after embedding.

Modern synthetic materials, however, have now made it possible to tackle the problem of reinforcing laminated cores with prospects of success. After extensive tests, taking account of the problems previously mentioned, successful methods have been evolved for reinforcing soft magnetic-alloy cores with plastics, without appreciably altering their magnetic properties. The plastics used should have minimum shrinkage, and the proportion of plastic relative to the core volume should be kept at a low value. With these processes, even cores of highly sensitive materials, e.g., a 50% nickel-iron with a rectangular hysteresis loop, can be reinforced without significant changes in its characteristic (Fig. 1).

The embedding procedure is also important for cores which are to be subsequently sectioned. For these cores reinforcing with resin is a most difficult problem. Since it is required that such cores should be as rigid as possible to avoid deformation, a firmly embedded assembly would seem desirable ; on the other hand, some compromise is needed to prevent deterioration of the core by mechanical stresses.

In addition, there are various other applications of these new embedding procedures ; thus, for instance, E- or U-shaped stampings can be bonded together into packs, particular mention being made of stampings for magnetostrictive vibrators.

Improvement in Magnetic Properties by Induced Stresses

As previously stated, the magnetostriction of nickel is negative, i.e., its orientation is impeded by tensile stresses and facilitated by compressive stresses. With compressive stresses, its hysteresis loop can be modified into a practically rectangular shape. Moreover, the remanent magnetism can be increased from its usual value (around 40% saturation) up to 90% or even higher, by applying compressive stresses of the order of 10 kg/mm^2. Stresses of this magnitude can be generated by mechanical means, which, however, are very cumbersome and in most cases cannot be used owing to the additional space required. It is, however, possible to generate definite mechanical stresses in a simple manner in a magnetic core by embedding it in a synthetic resin. In the case of a nickel ring, for instance, embedded in a cast synthetic resin, the remanent magnetism has been raised from 40% to more than 80% of the saturation value.

Besides nickel, certain magnetic oxides can obtain a nearly rectangular hysteresis loop under compressive stresses[6]. Thus, the remanent magnetism of nickel-zinc ferrites, which have negative magnetostriction, can be raised from 46% to about 85% saturation by casting with synthetic resin[6]. The most suitable compressive stress is around 1 kg/mm^2.

By means of deliberately applied compressive stresses, it is also possible to increase the permeability ratio, i.e., that of permeability after a period of premagnetization to initial permeability. For a 50% nickel-iron this ratio can thus be raised from 30 to 80%, approximately.

In most materials, particularly those with positive magnetostriction, compressive stresses cause a flattening of the hysteresis loop and a reduction in the remanent magnetism. Reduced remanence is an advantage in cores required for pulse transmission applications, where no premagnetization can be used. As the pulse height is determined by the difference between saturation induction and remanence, a decreased value of the latter represents a corresponding increase in the pulse height and hence an increase in the amount of power that can be transmitted.

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The Behaviour of Transistors at High Current Densities

By F. H. Stieltjes and L. J. Tummers. (From *Philips Technical Review*, Vol. 18, No. 2, 1956/57, pp. 61–68, 8 illustrations.)

According to the simple theory of the junction transistor[1], the current amplification factor α of a transistor does not depend upon the applied emitter voltage V_e. In practice, however, when the current is increased (by raising the emitter voltage) the value of α, after an initial increase, declines to a value far below the initial value valid for low current densities. The failure of the simple theory is attributable to the fact that one of its premises is no longer tenable when the current density is raised. In fact, the minority concentration in the base then ceases to be very small in comparison with the majority concentration at the same spot. This has two important consequences, i.e., (1) the minority current in the base is no longer purely a diffusion current, for the electric field also begins to have a marked effect; and (2) the expression previously given[1] for the minority concentration in the boundary planes of a *P-N* junction is no longer valid. These two facts were first pointed out by Webster[2] and Rittner[3], who explained the form of the 1-α curve, in which only a fraction α of the total emitter current I_e reaches the collector, so that 1-α can be considered as a loss, which is at a minimum for a relatively low current density but which rises continuously as I_e is further increased. In this article, however, the authors deduce that the value of the current density at which α becomes troublesome can be substantially raised by the incorporation of a large number of acceptor atoms in the emitter material. In the Research Laboratories at Eindhoven good results have been obtained by the addition of a small amount of gallium to the indium used in the preparation of the emitter of a *P-N-P* alloy transistor.

Breakdown of the Simple Theory at High Current Densities

In this article, hole and electron concentrations are indicated by p and n respectively. The suffix P or N indicates whether a magnitude is related to a *P-* or to an *N*-region. It is thus immediately apparent whether a minority concentration (p_N and n_P) or a majority concentration (p_P and n_N) is concerned. The corresponding equilibrium concentrations are denoted by an additional suffix 0. The suffixes p and n are used to denote whether a quantity refers to holes or to electrons, e.g., J_p stands for the hole-current density, and D_n for the diffusion constant for electrons.

Effect of the Field on the Minority Current at High Current Densities:—

Consider the emitter junction of a *P-N-P* transistor. The emitter efficiency γ, i.e., the fraction of the emitter current transported by holes, lies close to unity for a good transistor. In the base the current from emitter to collector is therefore almost entirely composed of holes; the electron current is here virtually zero. At every point of the base where the hole concentration (minority concentration) is very small with respect to the electron concentration (majority concentration), i.e., at every point where

$$p_N/n_N \ll 1 \quad .. \quad .. \quad .. \quad (1)$$

applies the hole current is almost a pure diffusion current. If the hole concentration is so high that eq. (1) is no longer valid, then the electric field also plays a part in determining the hole current.

Now, assume that hardly any space charge can arise outside a *P-N* junction (neutrality condition). This implies that the concentration gradients for the two sorts of charge carriers are the same in any cross-section outside a *P-N* junction (Fig. 1). Thus, there is not only a diffusion current of holes, but also of electrons; indeed, the electron diffusion current is about twice as great as the hole diffusion current, for the diffusion constant for electrons is about twice that for holes. Diffusion causes holes and electrons to move in the same direction and hence the electric current densities, designated by J_{pD} for holes and J_{nD} for electrons, are of opposite sign, so that

$$J_{nD} = -2\,J_{pD} \quad .. \quad .. \quad .. \quad (2)$$

If, in spite of this, the total electron current remains (virtually) zero, then there must be an electric field that brings about a field current of electrons (with a density J_{nF}) which cancels out the electron diffusion current, i.e., $J_{nF} = -J_{nD}$.

Replacing J_{nD} in eq. (2),

$$J_{nF} = 2\,J_{pD} \quad .. \quad .. \quad .. \quad (3)$$

If the concentration of electrons is very high, compared with that of the holes, the field creates a hole current J_{pF} which is negligible with respect to J_{nF}, and, in accordance with eq. (3), also with respect to J_{pD}; if this condition is

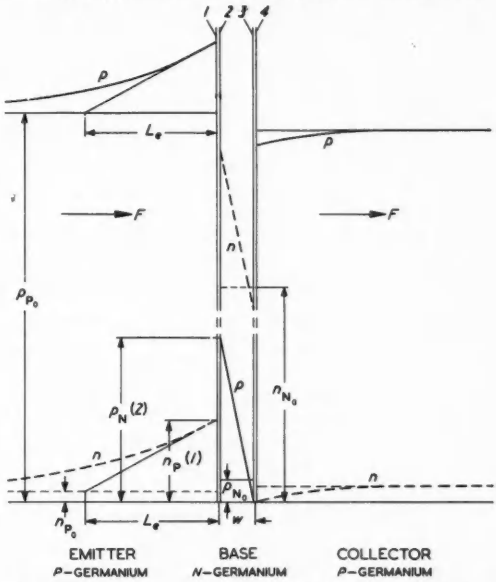

Fig. 1. Hole concentrations (solid lines) and electron concentrations (dotted lines) in a *P-N-P* transistor.
(1), (2), (3), and *(4)*: Equilibrium concentrations of holes and electrons in the emitter.
p_{P0} and n_{P0}: Equilibrium concentrations of holes and electrons in the emitter.
p_{N0} and n_{N0}: Equilibrium concentrations of holes and electrons in the base.
$n_P(1)$ and $p_N(2)$: Minority concentrations in the boundary planes *(1)* and *(2)*, fixed by the voltage applied between *(1)* and *(2)*. In the boundary planes *(3)* and *(4)* the inverse voltage between these planes fixes the minority concentrations at zero.
L_e: Diffusion length in the emitter.
w: Thickness of base.
F: Electric field, acting in the direction of the arrows.

not satisfied, however, the field current of the holes cannot be disregarded.

The electric neutrality of the base has the consequence that the difference between the electron concentration n_N and the hole concentration p_N is the same at any point and is thus equal to the difference between the equilibrium concentrations n_{N0}—p_{N0} (Fig. 1). In this connection, it should be remembered that the net charge of the mobile charge carriers is balanced by the net charge of the (fixed) donors and/or acceptors present ; electric neutrality does not therefore imply that $p_N = n_N$.

If p_{N0} is neglected, in comparison with n_{N0},

$$n_N - p_N = n_{N0} \quad .. \quad .. \quad .. \quad (4)$$

This being so, eq. (1) is equivalent to

$$p_N/n_{N0} \ll 1$$

since, if either of these conditions is satisfied, it follows from eq. (4) that $n_N \approx n_{N0}$, so that the other condition is also fulfilled.

If this condition is satisfied in cross-section (*2*), (Fig. 1), i.e., if

$$p_N(2)/n_{N0} \ll 1 \quad .. \quad .. \quad .. \quad (5)$$

it is evidently satisfied elsewhere in the base, as may be seen from Fig. 1. Hence, if it is assumed that eq. (5) is satisfied, it may be concluded that the hole current in the base is almost exclusively a diffusion current. Its current density J_p is given by

$$J_p = qD_p \frac{p_N(2)}{w}$$

where q is the magnitude of the electronic charge, D_p is the diffusion constant for holes, and $p_N(2)/w$ is the concentration gradient for the holes (Fig. 1). Since the electron current is negligible, J_p is equal to the total current density J. Hence, it follows from eq. (5) that

$$J \ll qD_p \frac{n_{N0}}{w} \quad .. \quad .. \quad .. \quad (6)$$

If, therefore, the current density becomes so high that eq. (6) is no longer satisfied, then condition (5), from which it was deduced, cannot be fulfilled either, and consequently the minority concentration in the base is not everywhere negligible with respect to the majority concentration.

That this situation can occur in practice becomes evident when the numerical values applicable to a normal *P-N-P* transistor, chosen as an example, are inserted in eq. (6).

The equilibrium concentrations in the emitter are, say:

$$p_{P0} \approx 5 \times 10^{18} \text{ cm}^{-3}, \text{ and } n_{P0} \approx 10^8 \text{ cm}^{-3},$$

and in the base

$$n_{N0} \approx 5 \times 10^{14} \text{ cm}^{-3}, \text{ and } p_{N0} \approx 10^{12} \text{ cm}^{-3}.$$

Let the base thickness be

$$w \approx 50\ \mu = 5 \times 10^{-3} \text{ cm}.$$

The diffusion constants of holes and electrons are

$$D_p = 44 \text{ cm}^2/\text{sec}, \text{ and } D_n = 88 \text{ cm}^2/\text{sec}.$$

The average life of the holes in the base, determined by recombination in the interior and at the surface of the base, is

$$\tau_b \approx 15\ \mu\text{sec}$$

The area of the emitter junction is 3×10^{-1} cm^2. As $q = 1{\cdot}6 \times 10^{-19}$ coulomb, from eq. (6), for this particular transistor the influence of the field on the hole current is negligible, provided that the current density

$$J \ll 0{\cdot}7 \text{ A/cm}^2,$$

i.e., as long as the emitter current is considerably less than 2 mA. Currents of a few mA, however, are not exceptional, whilst far heavier currents occur with transistors in output-amplifier circuits. In such cases the minority current in the base will no longer be purely a diffusion current, the field will have to be taken into account.

Minority Concentrations in the Boundary Planes of a P-N Junction :—

The theory previously put forward[1] was based on the assumption that the minority concentrations in the boundary planes (*1*) and (*2*) of a *P-N* junction are fixed by the applied voltage V at

$$n_p(1) = n_{P0}\, e^{qV/kT} \quad .. \quad .. \quad (7a)$$

$$\text{and} \quad p_N(2) = p_{N0}\, e^{qV/kT} \quad .. \quad .. \quad (7b)$$

For the sake of convenience, a new variable Z is introduced in place of V, and is defined as

$$Z = Q\, e^{qV/kT} \quad .. \quad .. \quad .. \quad (8)$$

$$\text{in which} \quad Q = \frac{p_{N0}}{p_{P0}} = \frac{n_{P0}}{n_{N0}} \quad .. \quad .. \quad .. \quad (9)$$

Q is thus the ratio of the equilibrium minority concentration at one side of the *P-N* junction to the equilibrium majority concentration at the other side, and is therefore a very small number. In the transistor chosen as an example, $Q = 2 \times 10^{-7}$. The equivalence of the two expressions for Q follows from the condition $p_{N0}n_{N0} = p_{P0}n_{P0}$ (the product of the equilibrium concentrations of majority and minority charge carriers is independent of the region considered). Z is evidently always positive : only if $V = -\infty$ will Z become zero. Now, let B be the ratio of the equilibrium majority concentration in the *P*-region to that in the *N*-region, so that

$$B = \frac{p_{P0}}{n_{N0}} \quad .. \quad .. \quad .. \quad (10)$$

In a transistor the equilibrium majority concentration in the emitter always substantially exceeds that in the base, so that B is numerically large. In the sample transistor $B = 10^4$.

Eqs. (7a) and (7b) can now be written more conveniently, as follows :—

$$n_P(1) = n_{N0}Z \quad .. \quad .. \quad .. \quad (11a)$$

$$p_N(2) = n_{N0}BZ \quad .. \quad .. \quad .. \quad (11b)$$

In view of the authors' intention to extend the theory to cover higher current densities, these formulae require correction. The values of the four unknown concentrations, i.e., the majority and minority concentrations in the two boundary planes of a *P-N* junction, are given for the general case by four equations which were worked out earlier by van Vessem.[4] By solving these equations the following minority concentrations are obtained :—

$$n_P(1) = n_{N0}Z \frac{1 + BZ}{1 - Z^2} \quad .. \quad .. \quad .. \quad (12a)$$

$$p_N(2) = n_{N0}Z \frac{B + Z}{1 - Z^2} \quad .. \quad .. \quad (12b)$$

which, for sufficiently small values of Z, reduce to eqs. (11a) and (11b). It can thus be seen, that both $n_P(1)$ and $p_N(2)$ would become infinitely great if Z equalled unity.

According to eq. (8), $V = (kT/q) \log_e(1/Q)$ if $Z = 1$. It has been shown by van Vessem[4] that this value represents the spontaneous potential difference (contact potential) between the N-region and the P-region. An external voltage compensating the contact potential would thus involve infinitely high minority concentrations and hence an infinitely great current. It will be clear that in practice the external voltages appearing across the P-N junction always lie below the contact potential. In the sample transistor a value of 0·3 V is obtained for the contact potential (at room temperature $kT/q = 1/40$ V). The voltages applied across the crystal may, however, be higher than 0·3 V, since the series resistance offered by the crystal itself causes a considerable potential drop.

Z, therefore, is always less than unity. It will be demonstrated in due course that even at a very high current density the emitter voltage is still so low that $Z \ll 1$. The terms Z^2 in the denominators of eqs. (12a) and (12b) may therefore be disregarded. Moreover, in view of the high value of B, Z may be neglected in comparison with B in the numerator of eq. (12b), but, for the same reason, it is not necessarily permissible to neglect BZ in comparison with unity in eq. (12a), so that

$$n_P(1) = n_{N0}Z\,(1+BZ) \qquad .. \qquad .. \quad (13a)$$

$$p_N(2) = n_{N0}BZ \qquad .. \qquad .. \qquad .. \quad (13b)$$

Eq. (13b) is identical with (11b), but (13a) can be replaced by (11a), only if $BZ \ll 1$, which implies, according to eq. (13b), that $p_N(2) \ll n_{N0}$. From eqs. (13a) and (13b) it follows that, as Z increases from zero (i.e., with increasing voltage in the forward direction and hence increasing current density), the ratio $n_P(1)/p_N(2)$, which in the simple theory was considered to remain constant (i.e., $1/B$) also increases. This causes a loss in emitter efficiency.

Transistor Losses as a Function of Current Density

The current amplification factor α is the product of the base efficiency β and the emitter efficiency γ. For the purpose of this article losses are considered, i.e., the total transistor loss $1 - \alpha$, the base loss $1 - \beta$, and the emitter loss $1 - \gamma$. Because $1 - \beta$ and $1 - \gamma$, and hence also $1 - \alpha$, are in practice always small with respect to unity, it follows from $\alpha = \beta\gamma$ that

$$1 - \alpha = (1-\beta) + (1-\gamma) \qquad .. \quad (14)$$

Once the behaviour of $1 - \beta$ and $1 - \gamma$ as functions of current density has been established, the behaviour of $1 - \alpha$ as a function of the same quantity will be known. It is first necessary, however, to examine more closely the effect of the electric field on the minority charge carriers in the base of a transistor.

Apparent Increase of the Diffusion Constant of Minority Charge Carriers owing to the Influence of the Field :—

Field and diffusion drive the minority carriers in the same direction (Fig. 1). The effect of the field may thus be regarded as an apparent increase in the diffusion constant. A fact of great importance is that, for very high minority concentrations, the apparent diffusion constant approaches a limit which is twice the actual diffusion constant. This can be explained as follows :— The hole current density J_p and the electron current density J_n, each written as the sum of the contributions of diffusion and field, can be expressed by

$$J_p = -q\,D_p\frac{dp}{dx} + q\,p\,\mu_p F \qquad .. \quad (15a)$$

$$J_n = q\,D_n\frac{dn}{dx} + q\,n\,\mu_n F \qquad .. \quad (15b)$$

where μ_p and μ_n represent the mobilities of holes and electrons. Apart from this, the Einstein relation expresses the logically acceptable fact that there exists a direct proportionality between the diffusion constant D and the mobility μ for particles having an electric charge of equal magnitude, so that

$$\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = \frac{kT}{q} \qquad .. \qquad .. \qquad .. \quad (16)$$

Finally, it is known, from the neutrality condition (valid for regions outside a P-N junction), that the concentration gradients for holes and electrons are equal, i.e.,

$$\frac{dn}{dx} = \frac{dp}{dx} \qquad .. \qquad .. \qquad .. \quad (17)$$

By eliminating F from eqs. (15a) and (15b) and using eqs. (16) and (17),

$$J_p = -q\,\frac{1+\dfrac{p}{n}}{1-\dfrac{J_n}{J_p}\dfrac{\mu_p}{\mu_n}\dfrac{p}{n}}\,D_p\frac{dp}{dx} = -q\,D_p'\frac{dp}{dx} \qquad (18)$$

This expression for J_p has the form applicable to a diffusion current density. The influence of the field is expressed in the substitution of the apparent diffusion constant D_p' for the ordinary diffusion constant D_p. In an N-region, where p_N is written instead of p, after substitution from $\mu_p/\mu_n = \frac{1}{2}$ and from $n_N = p_N + n_{N0}$ (neutrality condition), it is found that

$$D_p' = \frac{1+\dfrac{p_N}{p_N+n_{N0}}}{1-\dfrac{J_n}{2J_p}\dfrac{p_N}{p_N+n_{N0}}}\,D_p \qquad .. \quad (19a)$$

As the current in the base of a transistor is mainly composed of holes, $J_n/J_p \ll 1$,

$$D_p' = \left(1+\frac{p_N}{p_N+n_{N0}}\right)D_p \qquad .. \quad (19b)$$

this changing for very high values of the minority concentration p_N into

$$D_p' = 2\,D_p \qquad .. \qquad .. \quad (20)$$

Reduction of Base Losses at High Current Densities:—

Owing to the effect of the field in the base of a P-N-P transistor at high current densities, the holes are transported more quickly through the base and thus run less risk of loss through recombination. The base loss, therefore, will diminish at increasing current density. The hole concentration is always highest near the emitter, in cross-section (*2*) (Fig. 1). Here it will be most noticeable that the apparent diffusion constant D_p' deviates from the normal value D_p and it is here too that D_p' will come nearest to its limit of $2D_p$. At very high current densities (theoretically only at an infinitely high value) D_p' will reach the value $2D_p$ throughout the whole base (i.e., up to infinitely near the collector). The average time a hole spends in crossing the base will then be halved. If it is assumed that the average life τ_b of a hole in the base is independent of current density, then that proportion of

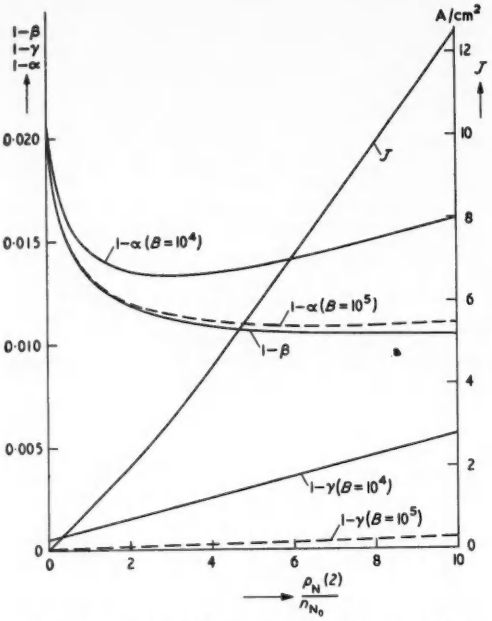

Fig. 2. **Base loss 1—β, emitter loss 1—γ, and current density J as functions of $p_N(2)$ (minority concentration in the boundary plane at the base of the emitter side), using n_{N0} (equilibrium majority concentration in the base) as the unit.**
Solid curves : Transistor chosen as an example, with $B = p_{P0}/n_{N0} = 10^4$.
Dotted curves : Transistor with equilibrium concentrations in base and emitter modified so that $B = 10^5$.

the total number of holes arriving per second in the base lost by recombination will also be halved. Hence, at increasing current density, the base loss approaches half the value it has at low current densities. Upon further analysis it can be found that the base loss $1 - \beta$ can be represented approximately by

$$1 - \beta = \frac{w^2}{2\,\tau_b D_p} \frac{1 + p_N(2)/n_{N0}}{1 + 2p_N(2)/n_{N0}} \quad .. \quad (21)$$

In Fig. 2, 1—β is plotted as a function of $p_N(2)/n_{N0}$, on the basis of the numerical values given in the example.

The premise that τ_b is independent of the current density, i.e., independent of the concentrations of holes and electrons, even when the concentrations are very high, is not immediately obvious. In such circumstances, every hole encounters a very large number of electrons, and it would be expected that the chance of recombination would increase for every hole, with the consequence that τ_b is shortened. In fact, however, recombination is a very intricate process. Direct recombinations occur very rarely ; as a rule, the process requires a number of intermediate steps, so that τ_b may well remain virtually constant. The assumption that it does so is supported by the results of measurements.

In the base of a *P-N-P* transistor the hole concentration gradually decreases towards zero from emitter to collector, so that, according to eq. (19b), the (apparent) diffusion constant D_p' gradually decreases towards D_p. Disregarding generation and recombination in the base, J_p may be considered to be independent of the position x, and, according to eq. (18), dp/dx must then gradually increase from emitter towards collector. The concentration curve of the holes, therefore, is no longer linear. However, the approximate eqs. (21) and (22) for the base and emitter losses are not affected by this slight deviation from linearity.

Increase in Emitter Loss at High Current Densities :—

It would be preferable if the total current through the emitter junction were carried entirely by holes ; in fact, however, a minor portion is composed of electrons. In the emitter, the electron current is a pure diffusion current, so that J_n is proportional[1] to $n_p(1)$. If the hole current in the base were also a pure diffusion current, then J_p would be proportional to $p_N(2)$ and J_n/J_p would thus be proportional to $n_P(1)/n_N(2)$. However, this ratio becomes higher as J increases, so that an increasing portion of J would be composed of electrons. There is a certain amount of compensation owing to the fact that the electric field comes to the aid of the hole current, so that initially J_p increases (proportionately) more rapidly than $p_N(2)$. Upon further analysis, however, it turns out that this effect of the field cannot fully compensate the effect of the increase of $n_P(1)/p_N(2)$, so that J_n/J_p always increases with J. The increase is accompanied by a falling off of the emitter efficiency γ and hence with an increase in emitter loss 1—γ. The analysis shows that the expression for 1—γ requires a correction factor $(1 + p_N(2)/n_{N0})$, so that

$$1 - \gamma = \frac{D_n\, w}{D_p\, L_e\, B} \left(1 + \frac{p_n(2)}{n_{N0}}\right) \quad .. \quad (22)$$

in which B again is given by eq. (10). L_e represents the diffusion length in the emitter (Fig. 1). The solid curve in Fig. 2 applies to 1—γ plotted for the example. In this connection, it should be noted that the concentration change of the electrons in the emitter as shown in Fig. 1 is not quite as it is in fact. The thickness d_e of the emitter is very small (e.g., 20 μ). At the point of contact with the electrode, equilibrium concentrations occur. Owing to this, the concentration gradient of the electrons in cross-section (*1*) is not determined by L_e, but by d_e. Consequently, L_e has been taken as 20 μ in the evaluation of eq. (22).

The total loss 1—α, consisting, according to eq. (14), of the sum of emitter and base losses, is also plotted in Fig. 2 as a function of $p_N(2)/n_{N0}$. This diagram further shows the current density $J(=J_p)$, and from this a curve showing 1—α as a function of J may be derived.

It appears from the curve for J in Fig. 2 that J is already very large when $p_N(2)/n_{N0} = 10$. It follows from eq. (13b) that in this case $BZ = 10$, so that, with $B = 10^4$, $Z = 10^{-3}$. Neglecting Z^2 with respect to 1, and Z with respect to B, as was done in the derivation of eqs. (13a) and (13b), was therefore perfectly justified.

Reduction of Transistor Losses

Eqs. (21) and (22) show how various quantities influence transistor losses. The influence of the factor B, which is defined by eq. (10), is of particular importance. The base loss is evidently independent of B, whereas 1—γ is inversely proportional to it. If, for example, B is multiplied by a factor of 10, the slope of the curve for 1—γ will become ten times smaller. Only for much larger values of $p_N(2)$, then will 1—α (dotted curve in Fig. 2) diverge perceptibly from 1—β. Analysis shows that

$$J = q\,\frac{D_p n_{N0}}{w} \left\{ 2\,\frac{p_N(2)}{n_{N0}} - \log_e \left(1 + \frac{p_n(2)}{n_{N0}}\right) \right\} \quad (23)$$

an expression in which B does not appear, so that the curve J in Fig. 2 is independent of the value of B.

In order to raise the value of $B (= p_{P0}/n_{N0})$, an attempt may be made to increase p_{P0}, the concentration of the holes in the emitter. This can be done by incorporating a large number of acceptor atoms in the germanium of the emitter[4]. For the provision of acceptor atoms, indium is often used, a substance which offers certain advantages in the manufacture of alloy transistors. As regards its solubility in germanium, however, another acceptor element such as gallium seems preferable, in view of the fact that the highest p_{P0} value attainable with indium is approximately 5×10^{18} cm^{-3}, whereas with gallium, which is much more soluble in germanium, a concentration ten times higher can be attained. On the other hand, gallium has certain properties which render it unsuitable as a direct substitute for indium. Experiments have been carried out using an acceptor material consisting of indium in which some gallium had been dissolved. In this way, gallium can be dissolved in the germanium together with the indium, with the result that p_{P0}, and hence the factor B, can be made ten times greater. The advantages of indium from the manufacturing point of view are thus combined with the superior solubility of

(*Concluded on page 398*)

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U.S.A.

Friction in a Close-Contact System

By W. Claypoole. (From *Mechanical Engineering*, Vol. 78, No. 6, June 1956, pp. 529–532, 7 illustrations.)

A survey of the literature of friction over the past 50 years or so reveals that workers in this field have developed a vast and growing awareness of the complexity of the phenomena associated with a very thin lubricating film between rubbing surfaces. This paper discusses, on a theoretical basis, certain fundamental aspects of the problem of close-contact friction, and presents experimental evidence in support of the inferences drawn.

The term " close contact " is used to describe a friction system in which two solid test specimens, separated only by a thin film of foreign material, are brought into contact with each other under pressure. The geometry of either or both of the contacting surfaces may be rounded or flat, and their mechanical finish may vary from rough to smooth. If the separating film is oil, its thickness may vary within relatively wide limits, depending on the degree of surface finish. In any event, its maximum thickness must not be greater than the maximum height of opposed surface elevations.

It is desirable at the outset to attempt a clarification of such terms as " clean " and " smooth ". In the absolute sense a clean surface implies the complete absence of any material other than that of which the surface is the outer boundary. Such a concept would exclude automatically the presence of an adsorbed film of water or of gas derived from the atmosphere. Under selected conditions and by the use of special techniques, it is possible to make a very close approach to absolute surface cleanness.

All common metals exposed to air acquire a contaminating film, usually an oxide, the result being that the short-range field of force resident on the surface of the native metal is now masked or neutralized. It is this sealing-off mechanism which is responsible for so many striking differences in the physical and chemical properties of clean and contaminated surfaces.

Concept of Surface Smoothness

Surfaces of perfect figure and smoothness are, and must remain, geometrical abstractions. Molecular smoothness, however, is a practicable possibility and is exhibited in nature by the still, clean surface of a liquid subjected to the action of surface-tension forces. However, the " degree " of molecular smoothness of the surface of a liquid, e.g., water, may vary within wide limits, vapour pressure being the major factor concerned. The surface of the water may be regarded as in a state of violent molecular agitation which continues during the process of evaporation. On the other hand, the surface of mercury is comparatively quiescent, partly because the molecules have much less mobility, but mainly because the rate of loss of surface molecules is so very small. In effect, the degree of smoothness of the surface may, without much error, be equated to the dimensions of the mercury molecule.

When mercury passes from the solid to the liquid state, the influence of surface-tension forces vanishes. The metal assumes a crystalline structure and the surface appears dull, this behaviour being common to all metals. Glass, on the other hand, has an amorphous structure. The only significant difference between molten and solid glass is one of viscosity, and it might be expected that the surface of glass after solidification would exhibit the same degree of smoothness as when molten. This, however, is not the case. There are definite indications of the presence of both large- and small-amplitude surface ripples, presumably generated while the viscosity of the cooling glass is rapidly rising to its very high final value.

No mechanical operation involving the removal or displacement of metal can result in the degree of smoothness automatically attained through the agency of surface-tension forces. It is equally impossible to match the surface geometry associated with the natural process. Johansson precision gauge blocks exhibit what is probably (with metals) the highest attainable degree of dimensional accuracy and surface smoothness. It is certain, however, that the processed surface of a gauge block is covered with a multitude of tiny irregularities. When two such surfaces are wrung together, a tension

of some 400 psi is required to separate them. The most reasonable explanation of this strong adhesion is that the tops of a very great number of opposed elevations are brought so close together that short-range molecular forces interact. In effect, when one such surface is made to slide over the other, exceedingly tiny metallic junctions or welds are rapidly formed and broken. The resistance to shear of each individual weld is very small, but the aggregate shear strength, as reflected in the value of sliding friction, may be quite high.

Ordinary shop methods of finishing fail to produce surfaces exhibiting the characteristic behaviour of precision blocks when wrung together. It is proposed to enquire into the basic mechanism responsible for this difference. This can be done most easily by setting up a practical model of a close-contact system constructed to specification, and to predicate its probable behaviour under specified conditions.

At the outset it is necessary to clarify the term " contact " by adopting definitions to cover two operating conditions:—

(a) A bearing contact is one which, under equilibrium conditions, assumes its proportionate share of the normal load. The sum of the separate bearing-contact loads is equal to the applied normal load.

(b) A clean contact is one in which the native substrate material of opposed solid surfaces comes into molecular contact. The load at such a contact is increased by the interaction of surface atomic fields.

In the following, the qualifying terms " clean ", " true ", " actual ", or " real ", as applied to areas of contact between opposed metal surfaces, will be regarded as synonymous.

Practical Model of Friction System

Specification : Assume that the specimens are of heat-treated steel, ground, lapped, and polished to the best possible finish, that each surface is overlaid with a single layer of oriented molecules, and that the normal load is constant. Apart from the terms of this specification, the known facts concerning the mechanical and physical state of the specimens are as follows :—

(a) Between the free surface and the true crystalline body of the metal there is a disorganized zone containing highly stressed metal distinctly amorphous in nature.

(b) The immediate surface (Beilby layer) will be metal in the amorphous state.

(c) The free surface will be a continuous tarnish film, usually of oxide, possibly in an amorphous state. Miscellaneous contaminants may also be present.

Topography of Surfaces : Departures from geometric flatness appear as surface waves of relatively large amplitude (pitch) and relatively small height above and below a geometric plane, while departures from geometric smoothness appear as a close pattern of tiny surface irregularities superimposed on the contours of the waves.

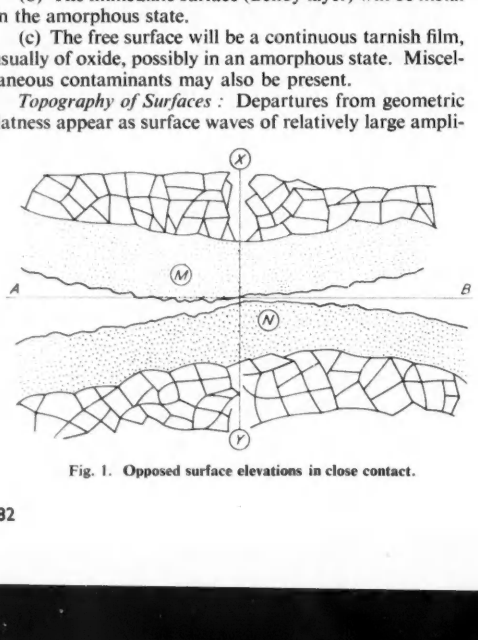


Fig. 1. Opposed surface elevations in close contact.

Conditions of Approach : In Fig. 1, *M* and *N* represent the tops of two opposed elevations (waves) which have been brought together along the line of approach *X-Y* normal to the reference plane *A-B*. It is safe to assume that the waves on a polished surface are rounded in contour. This assumption has been adopted in the diagram. Also indicated is the presence of very small irregularities on the contours of the rounded elevations. There is a low probability that the elevations meet exactly " head on " which, in turn, implies a high probability that the planes of contact are tilted at random with respect to the plane *A-B*.

Even when the utmost care is taken in the operation of bringing the surfaces together, it is extremely unlikely that the line of approach will exactly coincide with the line *X-Y*. Furthermore, because of the presence of irregularities on the wave contours and because of the tilt of the plane of contact, it is extremely likely that some degree of slip will occur at the moment of contact.

Analysis : Pressures developed when very small irregularities on opposed surfaces are brought together under load may reach values far exceeding the elastic limit, thus causing surface flow of the material of the irregularities. The immediate result is disruption of the protecting tarnish film, which travels with the displaced metal. What is even more important, the bonded oil molecules also travel with the flowed metal, and none of the bonded molecules in adjacent undisturbed areas can move in. There is thus a very strong tendency towards the exposure of clean metal, the result being that molecular forces come into action at the exposed spots, thus providing the ultimate reason for the creation or static resistance to relative tangential movement of the opposed surfaces.

In the model under consideration, the process described for a single pair of opposed elevations is repeated at a great number of similar oppositions randomly distributed over the whole area common to both surfaces. It must not be assumed, however, that the effects occurring at all of the many oppositions are identical either in kind or in magnitude. Deformation pressures may vary widely, as determined by the dimensions of the irregularities, thus causing variations in the areas of clean metal exposed and, as a consequence, variations in the values of the molecular forces coming into action.

The question now arises as to the nature and order of magnitude of the resistances developed at the exposed areas. Let it be assumed, as is highly probable, that both the tarnish film and the film of oriented oil molecules originally present on both surfaces have been removed as a result of plastic flow at the contacting irregularities, thus permitting clean metal to come into molecular contact across the interface. The inevitable result is that a fusion or weld will be formed. Relative tangential movement will shear the weld. The force required is determined by the dimensions of the junction and the elastic constants of the metal. The strength in shear of an individual weld is very small but, since there is a large number of such tiny welds distributed over the common interface, the force required to shear them all (value of static friction) will be in the measurable range. The greater the total area of clean contact, the greater will be the value of static friction. Two factors operate to increase the area of clean contact :—

(a) An increase in the normal load, leading to more extensive plastic deformation and surface flow.

(b) Improvement in surface flatness, which tends to increase the number of contacts between opposed surface irregularities.

Following this argument it would appear that the flatness factor is mainly responsible for the difference in behaviour of precision gauge blocks and contacting surfaces finished by ordinary shop methods. It is to be recognized that it is only at or near the tops of opposed elevations that clean contacts can be established. A reduction of surface waviness tends towards an increase in the number of close contacts made between opposed surface irregularities. Each of these close contacts is potentially a clean contact, i.e., a focal point for the generation of molecular forces and the formation of a minute weld.

Surface Film : Any discussion of frictional behaviour in a close-contact system must take into account the important role played by the surface tarnish film and its overlay of oriented oil molecules. It is fortunate that a protecting film is present ; otherwise, contacting metal surface in engineering practice would weld together immediately after initiating relative sliding under load. Moreover, this would not be averted by the presence of an oil monolayer bonded to the contacting surfaces, since such a film has the same physical properties and may be considered an integral part of the substrate. It is only when an oil film has a thickness of the order of 4 to 6 molecular layers (about $\frac{1}{2}$ microinch) that the constituent molecules have sufficient mobility to move onto suddenly exposed metal and thus afford some measure of insurance against the incidence of surface damage.

It has been shown that an increase in the normal load, by virtue of plastic deformation and surface flow, increases the area of clean contact and therefore the value of friction. It is evident that the presence of a surface film of oxide serves to set an upper limit to the ratio actual/apparent area of contact. The tarnish film is a permanent feature in the interface. It may, under conditions of high rubbing load, be dislodged and even ground up into fine debris, but it cannot be squeezed out.

In a previous paper* a sensitive friction tester was described. The normal load was 1 gram and the length of a rub track of a convex glass lens on a glass flat was of the order of a few thousandths of an inch. The instrument stood on a 40-lb cast-iron plate separated by a thick layer of absorbent cotton from a massive block of concrete built on bedrock. Among the materials tested was pure ricinoleic acid. It had been reported that under favourable conditions of exceedingly smooth surfaces the measured value of the static coefficient was " vanishingly small ", and had been attributed in part to the effects of mechanical disturbances. These may include a variety of superimposed elastic waves and rigid body movements at the contact point. The corresponding inertia forces may have relative components instantaneously additive to the applied tangential force and those instantaneously subtractive from the normal load, thus tending to initiate slip at lower apparent frictional coefficients.

In an effort to reduce the effects of incoming vibration to the lowest attainable limit, a Julius-type suspension for the friction tester was designed. A sensitive optical device capable of indicating mechanical disturbances at the contact spot of a fraction of 1 micron now gave negative results. Friction tests made after the installation of the vibration-isolation suspension then exhibited no abnormal behaviour, thereby confirming the view that " vanishingly low " static coefficients were referable to the disturbing effects of incoming vibrational energy.

Additional confirmation was afforded by the use of a device by which forced vibrations were introduced into the system. This device embodied a disc driven at 100 rpm by a clockwork motor, and a 5-gram mass mounted on the disc, with provision for varying its eccentricity from zero to 3 cm in steps of 0·5 cm.

Results

Fig. 2a is based on a photographic record of a test made on ricinoleic acid before the installation of the Julius suspension and shows, after a slip of 125 microns, an apparently vanishing value of friction.

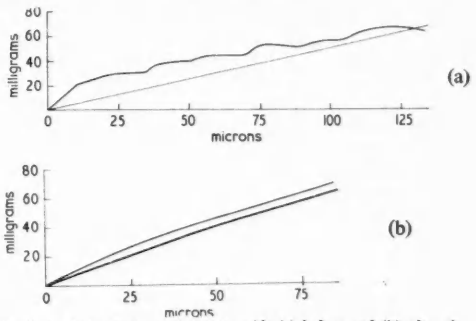


Fig. 2. Friction tests on ricinoleic acid, (a) before and (b) after the installation of the Julius suspension.

Fig. 2b is based on a photographic record of a similar test on ricinoleic acid after the installation of the Julius suspension, with the vibrator in place and with the weight set at an eccentricity of 3 cm. The introduction of a forced vibration, even of relatively low intensity, results in a friction graph showing a striking similarity to that in Fig. 2a.

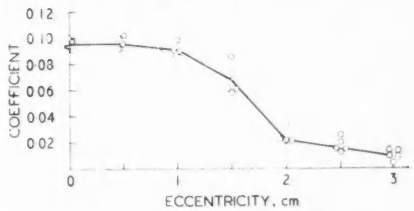


Fig. 3. Friction tests on ricinoleic acid, showing the effect on the static coefficient of friction of imposed vibration.

Fig. 3 is a graph showing the values found for the static coefficient of ricinoleic acid when the vibrator weight was set at 0·5 cm increments of eccentricity from zero to 3 cm. The mean locus of the values is a smooth transition between two horizontal levels. The fact that this graph is horizontal at the origin of the imposed inertia force suggests that extrapolation in the direction of lower intensities of mechanical disturbance than those maintained by the Julius suspension used, to the ultimate zero of mechanical disturbance, would then actually be the static coefficient of friction. The coefficient measured appears to be very nearly this static coefficient.

* " Further Developments in the Measurement of the Coefficient of Static Friction ", by H. D. Baker, W. Claypoole, and D. D. Fuller. Proceedings of the First National Congress of Applied Mechanics, 1952, pp. 23[illegible].

U. S. A.

Reclamation of Titanium Alloys by Vacuum Annealing

By D. N. Williams, R. I. Jaffee, and C. A. Bentley, Jr. (From *Metal Progress*, Vol. 69, No. 6, June 1956, pp. 57–59, 3 illustrations.)

It is only recently that erratic ductility, delayed cracking, and thermal instability of titanium-alloy components have been traced to excessive hydrogen. As a result, processing methods and controls have been changed, so as to avoid or minimize hydrogen absorption, and now the hydrogen content of titanium-alloy parts is consistently maintained at a safe low level.

With regard to titanium-alloy components which have been scrapped because of hydrogen embrittlement, it is now established that these can be reclaimed by vacuum annealing, thereby reducing the hydrogen content to a safe level. The value of a vacuum-annealing treatment may not, however, always be immediately apparent. Thus, for instance, in the case of a number of forged and stabilized Ti-140A compressor wheels, many were rejected because the material had failed to meet a minimum elongation specification of 15%, rejection rates varying from 27% to as high as 83%, depending on size. These wheels could be made ductile by heat treatment either in air or in vacuum, but the vacuum treatment was found to have additional benefit in improving thermal stability and in reducing strain-rate sensitivity.

Tangential bars were cut from the forged compressor wheels and heat-treated in air and in vacuum. In either air or vacuum, the ductility could be restored by annealing for several hours at about 1550°F, furnace-cooling to the stabilizing temperature of 1200°F, and holding for from 1 to 4 hr. Both the as-received material and the material heat-treated in air embrittled rapidly at 600 and 800°F, and there was a noticeable tendency towards embrittlement at 350°F. Heat treatment in vacuum, however, eliminated most of the instability. Presumably, this was due to the removal of hydrogen, which accelerates the decomposition of the beta phase, since alpha-beta alloys, because they are not in equilibrium at low temperatures, have an inherent instability. However, it is possible that the instability noted in the high-hydrogen material was caused by the precipitation of a hydride.

The microstructure of Ti-140A specimens, heat-treated in air and exposed for 200 hr at 800°F, consisted of white alpha particles in a light-grey beta matrix, with a third dark-grey phase which has not been identified (Fig. 1). This phase does not appear in vacuum heat-treated samples and may be attributed to the increased instability caused by hydrogen. It was also seen in samples exposed at 600°F, but was not nearly so prevalent and did not reproduce intact on repolishing. Although the new phase appeared only in high-hydrogen material, it was not possible to determine whether it was the product of normal beta decomposition accelerated by hydrogen, or a hydride.

High hydrogen contents embrittle alpha-beta titanium alloys in slow-speed tensile tests and static notch-rupture tests. The high-hydrogen Ti-140A specimens were tested in a notched stress-rupture test and failed in a brittle manner in about an hour or less when loaded at 120,000 psi. Vacuum heat-treated specimens could be loaded to 180,000 psi and held for at least 6 hr without failure.

It is apparent that hydrogen can promote both instability at elevated temperatures and marked strain rate and notch sensitivity at room temperature. Vacuum annealing of high-hydrogen titanium alloys (150 ppm or greater) can, therefore, be expected to improve not only the low-temperature ductility properties of the alloy but also its thermal stability. This latter effect should prove highly desirable in many elevated-temperature applications.

The cost of vacuum heat treating of titanium parts in a solid state depends, of course, upon the length of the cycle and the temperature required, and these in turn are determined by part sizes and whether they must be stress-relieved or degassed. Thin components such as blades evolve gas at a very fast rate. Thick forged parts such as compressor discs evolve gas more slowly, and sometimes require up to 36 hr at temperature for effective degassing.

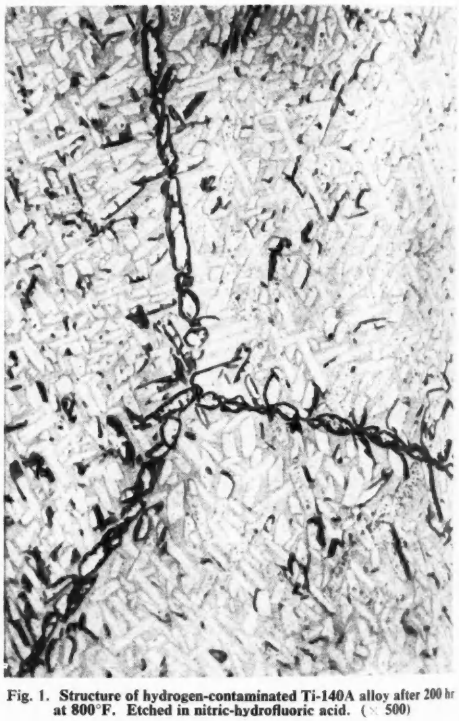


Fig. 1. Structure of hydrogen-contaminated Ti-140A alloy after 200 hr at 800°F. Etched in nitric-hydrofluoric acid. (× 500)

A very considerable amount of hydrogen-embrittled titanium scrap has been reclaimed by vacuum heat treatment with almost complete success. The pieces reclaimed include finish-machined or semi-finished titanium compressor rings, blades, tubing, sheet, and wire for jet-engine and aircraft manufacturers, and, although much of this material, despite costly machining operations, came in as scrap worth about 4*s.* per lb, it went out as fully restored metal, with greatly improved ductility and purity.

Degassing cycles may vary from 3 to 36 hr at temperatures ranging from 1250 to 1800°F, depending upon the kind and amount of contamination of the metal treated. For example, three Ti-140A jet-engine discs weighing 72 lb each were degassed by holding for 36 hr at 1250°F under a vacuum of less than one micron. Gas was

evolved rapidly during the first few hours of heat treating, and pressure increased to about 600 microns and then decreased slowly. After 36 hr at temperature the discs were cooled to below 500°F in 3¼ hr, the diffusion pump was shut off, and the retort cooled with a fine water spray.

The vacuum-tight retort is an all-important part of the furnace system. It is subjected to temperatures up to 1800°F, and must resist scaling and frequent thermal shock. Inconel is used for both retort and fixtures because of its high-temperature strength and resistance to scaling. Some of these retorts are still in good condition after 5000 hr of service.

In handling titanium, it has been found that extreme caution must be taken to protect it against contamination. While loading and unloading the charge, workers must wear white gloves, because fingerprints are almost impossible to remove from titanium except by sand- or vapour-blasting. The titanium parts tend to weld together at the degassing temperatures and they must be kept well apart with special Inconel fixtures.

Experience indicates that vacuum heat treating is an economical and indispensable method of degassing, annealing, and stress-relieving titanium and titanium-alloy parts. It should also be noted that it is a relatively new process in the U.S.A., and it is quite likely that it may eventually find an even greater use in improving the properties of other engineering alloys.

SWEDEN

Determination of Leakage in Compressed-Air Distribution Systems

By G. HJERTÉN, J. MUNCK AF ROSENCHÖLD, and T. ROHLOFF. (From *Jernkontorets Annaler*, Vol. 140, No. 6, 1956, pp. 425–450, 10 illustrations.)

The wastage of energy caused by leakage in compressed-air distribution systems is of great economic importance, amounting in Sweden to about 140 million kWh per year. This paper presents a basic theory of leakage and describes methods of leakage determination.

CONSIDERABLE amounts of energy are wasted every year through leakage in compressed-air distribution systems. In Sweden, for instance, the total installed capacity of normal compressors of from 7 to 12 atm gauge pressure and an effective output greater than 7 kW was approximately 48,000 m³/min in 1955. About 10% of these compressors are in reserve units, and the 90% in operation deliver about 80% of the full-load air capacity. It has been estimated, from a number of measurements in mines, in iron and steel works, and in workshops, that 18% of the total full-load capacity used, i.e., 7700 m³/min, is being lost through leakage. Actually, the true amount is closer to 23%, since the losses occur immediately after the compressors are in operation, whereas the full-load condition is only infrequently required. This 23% leakage represents an annual loss of energy of 140 million kWh. It should be noted that the air leakage loss in mines was found to be only two-thirds as high as that occurring in iron and steel works and engineering plants.

Valuable information on the subject of air leakage can be collected if answers can be given to the following questions:—(a) Are the compressed-air lines generally in a satisfactory condition? (b) How are the leakages distributed over the various parts of the system? (c) Is any carelessness involved in shutting off valves or during actual use? (d) To what extent are stringent measures applied to reduce air leakage or wastage?

EQUIVALENT LEAKAGE AREAS

In the past, air leakage has been indicated in cubic metres per minute of free air, or as a percentage of the installed compressor capacity. In this paper, air leakage is defined as the leakage flow from compressed-air distribution lines into free air, expressed in m³/min and referred to normal temperature T_N (15°C) and pressure p_N (1 atm abs.).

At first sight, it might seem more natural to express leakage in terms of flow at the particular pressure of the distribution system; however, as this flow varies with temperature and pressure, the above definition gives a more precise determination of the quantity involved.

The leakage condition can also be described more simply by giving the corresponding "equivalent leakage area". This area is that of a well-rounded orifice which will give the same flow of air as the actual leak positions. A properly designed bell-mouth orifice discharges from 98 to 99% of the theoretically possible air quantity, whereas a sharp-lipped orifice permits a discharge of only 80 to 85%.

The equivalent leakage areas of various portions of a system can be added together to obtain a total figure, providing a clear representation of the condition of an entire system. The equivalent leakage area can vary with the pressure in the system. Part of the leakage is constant, whereas other parts, owing to joint losses and cracks, vary with pressure. Temperature also has some effect; for instance, leakage may increase in cold weather, owing to contraction of pipelines and partial loosening of flanges. It is not easy to state what value of equivalent leakage area can still be regarded as permissible, since such an area depends on the extent and volume of the system, pipeline dimensions, the number of joints, air points, flexible hoses, etc. For distribution systems of more or less similar design and capacity (e.g., in mines), the equivalent leakage area A_e[mm²] can be related to the volume V [m³] of the system. Thus, specific equivalent leakage area A_{se} can be defined as

$$A_{se} = A_e/V \quad [\text{mm}^2/\text{m}^3] \quad .. \quad .. \quad (1)$$

and this is useful in comparative assessments. If the lines are connected to an air tank, the volume and leakage of the latter should not be included, since the volume of the tank predominates. Naturally, however, the A_{se}-value of the tank, which is of considerable interest, must be determined separately.

THEORY OF LEAKAGE

According to evidence available from a large number of investigations, an escape of air through leaks normally occurring in practice can be treated as an air flow with a

supercritical pressure ratio; in other words, if p_1 is the air pressure in the system, and p_0 is atmospheric pressure,

$$p_1/p_0 > 1{\cdot}892$$

this figure being obtained from $p_1/p_0 = (1+\gamma)^{\gamma/(\gamma-1)}$ with an adiabatic exponent $\gamma = 1{\cdot}4$. Under such conditions, the weight W_1 of air flowing per minute through an ideal orifice of equivalent area A_e can be calculated as

$$W_1 = 0{\cdot}238 A_e p_1/\sqrt{T_1} \text{ [kg/min]} \quad .. \quad .. \quad (2)$$

where T_1 = the air temperature in the system [°K].

The actual volumetric flow [m³/min] in the system q_1 and that referred to normal temperature and pressure q_N can be calculated as

$$q_1 = 0{\cdot}000697\ A_e \sqrt{T_1} \quad .. \quad .. \quad (3)$$

$$q_N = 0{\cdot}2\ A_e\ p_1/\sqrt{T_1} \quad .. \quad .. \quad (4)$$

The expression for q_1 shows that, if T_1 is constant and A_e does not vary with pressure, the leakage flow rate is independent of the pressure p_1 in the system and of the condition of the outside air, i.e., a constant volume of air of the condition inside the system will flow out per unit of time, regardless of p_1, p_N, or T_N. On the other hand q_N depends on p_1. If the working pressure is 7 atm gauge, so that $p_1 = 8$ atm abs. and $T_1 = T_N = 288$°K, the equivalent flow is

$$q_N = 0{\cdot}0946\ A_e \quad \text{[m³/min]} \quad .. \quad .. \quad (5)$$

This indicates that an equivalent leakage area A_e of 1mm² corresponds to a leakage flow of 94·6 litres per minute to the outside air.

It is also of interest to consider the rate of discharge when the system under pressure has been shut off from the air supply, so that its pressure will drop owing to leakage flow. The total weight of air M contained initially in the system is

$$M = 10^4 p_1 V/RT_1 \quad \text{[kg]} \quad .. \quad (6)$$

where the gas constant $R = 29{\cdot}27$, p_1 and T_1 being the time-dependent variables. The leakage flow per unit time t is therefore

$$W_1 = -\mathrm{d}M/\mathrm{d}t = M \frac{\mathrm{d}}{\mathrm{d}t}\left(\log_e \frac{T_1}{p_1}\right) \quad \text{[kg/min]} \quad .. \quad (7)$$

By means of this equation for $-\mathrm{d}M/\mathrm{d}t$, it is possible to calculate the leakage flow W_1 at any instant, if the total volume of the system is known and if the corresponding values of T_1 and p_1 are determined by measurement at the instant considered.

By combining eqs. (2) and (7), it is therefore possible to determine the instantaneous value of the leakage area A_e as a function of time during the discharge period as

$$A_e = 1437 \frac{V}{\sqrt{T_1}} \frac{\mathrm{d}}{\mathrm{d}t}\left(\log_e \frac{T_1}{p_1}\right) = 3309 \frac{V}{\sqrt{T_1}} \frac{\mathrm{d}}{\mathrm{d}t}\left(\log_{10} \frac{T_1}{p_1}\right) \quad (8)$$

The curve of the time-derivative of $\log_{10}(T_1/p_1)$ can be determined either graphically or numerically. As p_1 is a known function of time, the equivalent leakage area A_e can be plotted against p_1, instead of t. Thus, the results of the discharge test can be used to determine the leakage area under normal operating conditions with a constant working pressure p_1 in the system.

The resulting data characterize the behaviour of the system. It is usually found that A_e is approximately constant over a wide range of p_1- values, e.g., between 4 and 7 or between 9 and 12 atm gauge. However, if p_1 is increased very appreciably, e.g., from 7 to 12 atm, an increase in A_e must be expected.

It is also found that, contrary to what might be assumed, the temperature T_1 remains practically constant during the discharge. Investigations have shown that the heat entering from outside sources has sufficient time to compensate the drop in temperature caused by expansion of the air in the discharge process. Thus, with T_1 constant, the expression for the equivalent leakage area becomes

$$A_e = -3309 \frac{V}{\sqrt{T_1}} \frac{\mathrm{d}}{\mathrm{d}t}(\log_{10} p_1) \quad [\mathrm{mm}^2] \quad .. \quad (9)$$

If both A_e and T_1 are constant over a certain range of pressures p_1' to p_1'', then in this interval $\mathrm{d}(\log_{10} p_1)/\mathrm{d}t$ is constant. The leakage area in this case is obtainable as

$$A_e = \frac{3309\ V}{\sqrt{T_1}\ \Delta t} \log_{10}\left(\frac{p_1'}{p_1''}\right) \quad .. \quad (9a)$$

where Δt = time interval corresponding to $\Delta p = p_1'' - p_1'$.

The pressure during the discharge can also be evaluated as follows, for this particular range :—

$$\int \frac{\mathrm{d}}{\mathrm{d}t}(\log_{10} p_1)\mathrm{d}t = -\int \frac{A_e \sqrt{T_1}}{3309\ V}\ \mathrm{d}t$$

or

$$\log_{10}(p_1/C_1) = -C_2 t$$

For a simple result, let $p_1 = p_1'$ when $t = 0$. Then, $C_1 = p_1$. Moreover, $C_2 = A_e \sqrt{T_1}/3309V = \log_{10}(p_1'/p_1'')/\Delta t$; hence,

$$p_1 = p_1' \times 10^{-C_2 t} \quad \text{[atm abs.]} \quad .. \quad (10)$$

and this implies that the percentage pressure change per unit time is constant in the range of pressures p_1' to p_1''.

Methods of Determining Leakage

Leakage flow should be measured under conditions prevailing when no consumption is required. The state of the system should be ascertained with considerable care, so that measurements may be repeated, if necessary, under similar conditions to observe any variations in leakage flow. The localization of leakage can be achieved (a) by measuring the leakage flow of each individual section shut off from other parts of the system, and (b) by measuring the leakage flow at the compressor station, with the various sections of the system shut off one after the other. Method (a) is tedious but gives reliable values. With method (b) the leakage flow of a section is obtained as the difference between flow values before and after it is shut off. If the two flow values are nearly equal, however, their difference will be subject to a considerable percentage error, so that this method can give a very uncertain result.

Frequently, an appreciable proportion of the loss occurs in hose lines and other flexible connections. To determine this loss, the leakage flow of the pipeline system is measured, first with all air valves shut off, and then with all supply valves open. The difference between these two measurements gives the loss in hose lines, etc. Certain types of air-operated machines, e.g., rock drills, consume air as soon as they are under pressure ; this air consumption should not be regarded as a loss.

For the measurement of leakage flow there are three methods available, each with its merits and disadvantages, these methods being (1) the direct method, (2) the intermittent-charging method, and (3) the discharge method. Truly comparable results are obtained only by using the

same method and an identical routine procedure. It is advisable to measure leakage periodically, since what is desired is not so much absolute accuracy in figures but a constant check of any variations in the state of the system.

The Direct Method :—

Leakage flow can be determined directly, with a simple arrangement such as that shown in Fig. 1, using a flow-meter, or a totalizing device (which indicates the total quantity of air passing through it) in conjunction with a stopwatch.

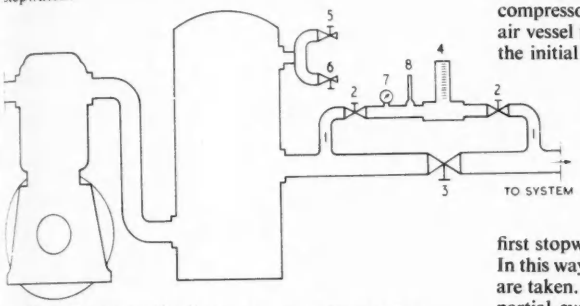


Fig. 1. Arrangement for direct measurement of leakage flow.

The metering device (4) and a pressure gauge (7) are located in a branch pipe (1) on the delivery side. The measuring section is provided with valves (2) at both ends, and there is also a valve (3) in the main duct. The metering device should have adequate capacity to indicate the largest expected leakage flow of the entire system ; it should also have sufficient sensitivity (with several sensitivity ranges, if necessary) to detect leakage flow in the smallest sections. The air vessel should be provided with a blow-off valve (5) for coarse adjustment and a smaller valve (6) for fine adjustment. A thermometer (8) is included, to obtain corrections for the flow readings.

For the test, the system is put under normal pressure, and then the compressor is adjusted to the lowest delivery capable of producing a leakage flow. Excess air is blown off through valves (5) and (6), which are adjusted until the gauge (7) shows a constant pressure. Valves (2) are opened, and valve (3) is closed. After regulating valves (5) and (6) so as to maintain a constant pressure in the air vessel for at least 10 min, the air flow, corresponding to the leakage flow, is read from the meter (4).

It is, of course, possible to install the measuring arrangement at some other position in the system, e.g., an air-supply point or an air vessel. The by-pass measuring system is then the same as in Fig. 1, except that the T-section with the blow-off valves (5) and (6) is arranged in the main duct, between positions (1) and (3). Measurements of this type in various parts of the system give more accurate results than the differential-leakage method (b) previously mentioned.

The direct method requires fairly expensive equipment, but an accurate flowmeter and the corresponding corrections are necessary for reliable results. The volume of the system and its variations in successive tests should, of course, also be carefully determined.

The Intermittent-Charging Method :—

When this method is employed, leakage flow is determined by evaluating the intermittent-operation factor of the load cycle according to which a compressor must be operated, in order to maintain a specified pressure in the system. If it is desired to measure by this means the absolute value of leakage flow, the capacity of the compressor used (in m³/min referred to compressor intake conditions) should be accurately known or determined in a separate calibration test. For the intermittent-charging method, two stopwatches and a good pressure gauge with a rapid response and a clear scale graduation are required.

For the measurement, the compressor is allowed to charge the system up to its normal delivery pressure. Then, the compressor control valve is shut off and the compressor is left under no load until the pressure in the air vessel falls off to a suitable value, e.g., 0·5 atm below the initial delivery pressure. When this limit is reached, one stopwatch is started, and the compressor is put under load by manual operation of the control valve. The watch is stopped when the pressure has risen by 0·3 atm, and the second watch is then started and the compressor output is cut off. When the pressure falls off by 0·3 atm the compressor is again put under load, and the first stopwatch is started again, and the other is stopped. In this way, a new cycle is initiated, and alternate readings are taken. The times t_1', t_1'' . . . and t_2', t_2'', . . . for each partial cycle related to the load and no-load condition, respectively, are noted.

Four or five cycles are carried out in succession so as to be sure that the compressor is operating under constant running conditions and to obtain good accuracy. The pressure/time diagram obtained from the test is shown in Fig. 2.

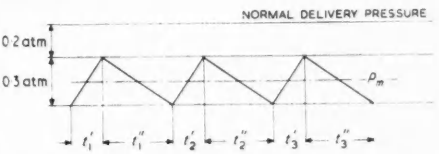


Fig. 2. Pressure/time diagram obtained by the intermittent-charging method.

The method assumes that no air is supplied to the system during the no-load period. When the load is removed from a reciprocating compressor by so-called "dead-space regulation", it is not uncommon for the compressor to continue to deliver some air during the no-load period. To avoid this, therefore, it is necessary to ensure that the compressor is provided with a delivery system which enables all the air in the intercooler to be discharged into the atmosphere during the no-load period.

The mean pressure (Fig. 2) is p_m (chain-dotted line) [atm abs.]. If q_1 [m³/min] is the leakage flow referred to system conditions, while q_N is the flow relative to normal atmospheric conditions, then

$$q_N = q_1 \frac{p_1}{p_m} \frac{t'}{t' + t''} \quad .. \quad .. \quad (11)$$

the value of q_1 being obtained from

$$q_1 = \frac{288 q_c p_i}{T_i} \quad .. \quad (12)$$

where q_c is the compressor delivery capacity [m³/min] referred to the pressure p_i [atm abs.] and temperature T_i [°K] at the compressor intake. This is converted to the equivalent flow value q_1 by taking $T_N = 288$°K and $p_N = 1$ atm abs. If the above value of q_N is used in the

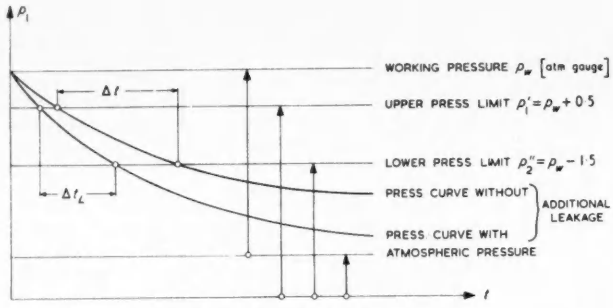


Fig. 3. Discharge with and without additional leakage.

previous equations for the equivalent leakage area A_e, then this is obtained as

$$A_e = 4{\cdot}97 \sqrt{T_1} \frac{q_1}{p_m} \frac{t'}{t' + t''} \quad .. \quad (13)$$

or, if $T_1 = 288°K$,

$$A_e = 84{\cdot}5 \frac{q_1}{p_m} \frac{t'}{t' + t''} \quad .. \quad .. \quad (13a)$$

This method has the advantage of requiring only very simple equipment. Its accuracy is less than that of the direct method and it is subject to random errors, caused, for instance, by a defective compressor valve. The valves should therefore be checked for satisfactory operation before starting each test. The method does not indicate the volume of the system, nor does it permit the leakage from a limited section to be determined unless the " differential-leakage " method is used.

If several compressors are available, the compressor selected for the tests should be one which, if possible, gives charging times at least as long as the leakage times. It is not advisable to operate the compressor under part-load conditions, since its delivery capacity is rarely determined with the same accuracy for lower loads as for full load. Compressors with dead-space regulation have a part-load capacity which may differ in a compressor calibration test and in a system leakage test if the quantity and temperature of the cooling water are different in the two cases.

The Discharge Method :—

This method is based on the determination of the rate of decrease of pressure in the closed system and requires knowledge of the total volume V. As this is difficult to calculate in extensive systems, the volume can be determined by an " additional-leakage " method.

The system is charged up to its normal working pressure p_1 or even 10 to 20% above this value, if possible. The compressor control is then adjusted to obtain the lowest load capable of maintaining this pressure for some 15 min, this being necessary in order to obtain uniform conditions in the system. The compressor is then stopped and isolated from the system. A measurement is taken with a stopwatch of the time Δt [min] elapsed while the pressure in the system falls off from a value p_1' (0·5 atm below the normal working pressure p_1) to another value p_1'' (2·5 atm below p_1).

From what has been previously stated, it can be considered that the equivalent leakage is constant in this pressure interval. Therefore, the equivalent leakage area A_e can be determined by means of eq. (9a); the specific leakage area is $A_{se} = A_e/V$ [mm²/m³], and the equivalent flow volume q_N is obtained from eq. (4). Referring again to eq. (9a), it is seen that A_{se} can be calculated without knowing the volume V.

Comparisons of system conditions can also be made by means of the following characteristic parameters: $C_3 = 662Vp_1 \times \log_{10}(p_1'/p_1'')$ with p_1 etc. as above, and $C_4 = C_3/T_1$, which gives $q_N = C_4/\Delta t$. Graphs of these various relations can be plotted to reduce to a minimum the evaluation work.

The " additional-leakage " method for determining the volume of the system will now be described. This method consists of comparing the results of a normal discharge test, performed as indicated above, with the results of measurements with an additional leakage of known equivalent area A_{eL} connected to the system. In this latter test the discharge between the same pressure limits p_1' and p_1'' occurs in a shorter period Δt_L (Fig. 3).

In addition to the parameter $A_e = C_e/\Delta t$ of the normal discharge test, a further quantity is evaluated, i.e.,

$$A_{eL} + A_e = C_e V/\Delta t_L.$$

By eliminating A_e from these two equations, the total volume V of the system is obtained as

$$V = \frac{A_{eL}\,\Delta t_L\,\Delta t}{C_e\,(\Delta t - \Delta t_L)} \quad .. \quad .. \quad (14)$$

C_e being determined from $C_e = 3309 \log_{10}(p_1'/p_1'')/\sqrt{T_1}$.

Conversely, by eliminating V, the equivalent leakage area A_e of the system can also be obtained as

$$A_e = \frac{A_{eL}\,\Delta t_L}{\Delta t - \Delta t_L} \quad .. \quad .. \quad (15)$$

It should be noted that these results assume that C_e is the same value for both tests, i.e., that T_1 is practically unchanged.

It is advisable to make the additional leakage fairly large, e.g., from 50 to 100% of the estimated equivalent leakage area of the system. A suitable arrangement is shown in Fig. 4.

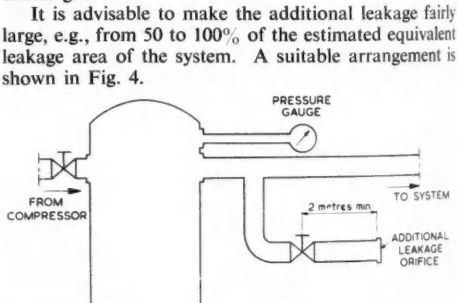


Fig. 4. Arrangement for determining the volume of a system by the additional-leakage method.

The additional leakage can be obtained by means of a suitable orifice, which is fitted at the end of a pipe about 2 metres in length, the pipe being connected to the system. This disc type of orifice is held in position by a threaded cap and can be replaced by a plate when the additional leakage is not required. The effective equivalent area A_{eL} of this particular type of orifice can be estimated from $A_{eL} = \alpha A$ [m²], where α is the flow coefficient and A the area of the orifice. The flow coefficient α is not constant for all conditions, its value depending on the size of the orifice and the pressure p_1 in the system; its value must therefore be determined experimentally.

British Industrial Developments

Nucleonic Power-Station Simulator

The most comprehensive nuclear power-station simulator yet built in Great Britain has recently been installed at the G.E.C. Simon-Carves Atomic Energy Group establishment at Erith, Kent. The simulator is an electronic analogue computer (Fig. 1) which can simulate the performance of a complete nuclear power station, and is the largest and most advanced of its type in the U.K. to be used exclusively for nuclear power studies.

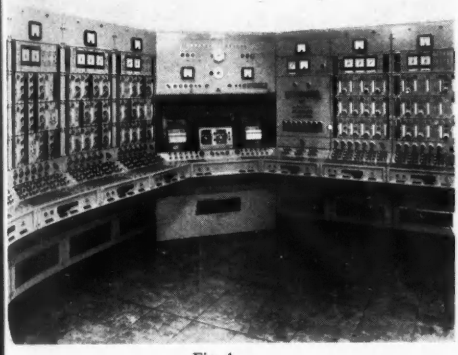


Fig. 1.

The use of an electrical analogue enables the behaviour of a particular unit or group of units in the plant to be predicted accurately and quickly without the need for long and laborious calculations. By setting the appropriate voltages on one section of the computer, the electrical circuits can be made to simulate the behaviour of the actual equipment and the results obtained in a matter of minutes as graphs on the recording instrument. More complex problems, involving the interdependence of several sections of the plant, can be dealt with equally well, and in these cases the saving of time and effort is even greater.

The flexibility of the computer was carefully considered during the design stages, with the result that it will be equally useful in the investigation of more advanced forms of reactor than the gas-cooled, graphite-moderated type now under development. A unique and most important feature of the new computer is that it has been designed to operate either as one large machine or as two completely independent smaller machines. It is thus possible to examine simultaneously two entirely separate problems—a time-saving advantage in cases where neither problem requires the use of the complete machine.

The computer is housed in its own room, the air in which is maintained at slightly above atmospheric pressure by fans above the false ceiling. This precaution ensures that all leaks are outwards and tends to eliminate the ingress of dust. A workshop is attached to the main computer room for the storage of instruments and for carrying out routine servicing and testing of computer units. The computer workshop will also be used for the construction and testing of auxiliary circuits for the machine as these become necessary.

In many of the problems encountered the time-scale is likely to vary from a fraction of a second to several hours. The computer normally operates in real time, and the performance of any section of the power station can be examined from the traces of two continuous high-speed pen recorders which allow four variables to be recorded simultaneously. Alternative indication of each section is provided by a cathode-ray oscilloscope. An additional advantage of real-time working is that actual units of control systems can be coupled into the simulator circuit and their behaviour analysed. For longer-term problems, such as the effects of xenon poisoning of the fuel, the rate of working can be accelerated.

The computer comprises a total of eight cabinets, arranged in " L " formation, with the control cabinet at the junction. One special cabinet is permanently connected to simulate the nuclear reactor itself, the remaining six being identical general-purpose cabinets which can be set up to simulate the performance of heat exchangers, control rods, blowers, turbo-alternators, or other components of the power-station plant. This arrangement allows the equipment to be used with a high degree of flexibility, and will enable a wide variety of problems to be studied.

Provision is made for the incorporation of 100 drift-connected amplifiers and 20 servo-multiplier units. At present, 84 amplifiers are available, any one of which can be used as a summing amplifier, integrator, or servo-amplifier. Two transit-time units are provided for the simulation of time delays, the output signal of each unit being the input signal delayed in time.

The simulator was manufactured by the Nuclear Division of Elliott Bros., of London, S.E.13, who also collaborated with the General Electric Company in the design of the machine.

Although the computer is one of the major items of equipment now in use at the atomic-energy department, other aspects of research are fully catered for, so much so that the department combines in one centre all the facilities necessary for research, design, and test work in the development of commercially built nuclear power stations. New laboratories have been built and equipped for the specialized work necessary on metallurgical and heat-transfer problems, and for testing prototype electrical and mechanical equipment. With engineering design and drawing offices, the department already occupies an area of 33,000 sq ft, and preparations are in hand for further large extensions.

The functions of the two materials research laboratories, one of which is illustrated in Fig. 2, are to assess the performance of materials for use in the present design of reactor and to carry out research into new and modified

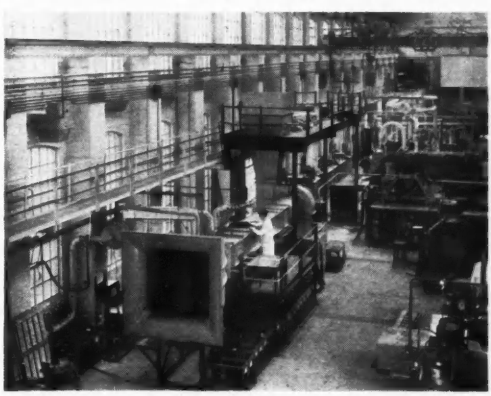
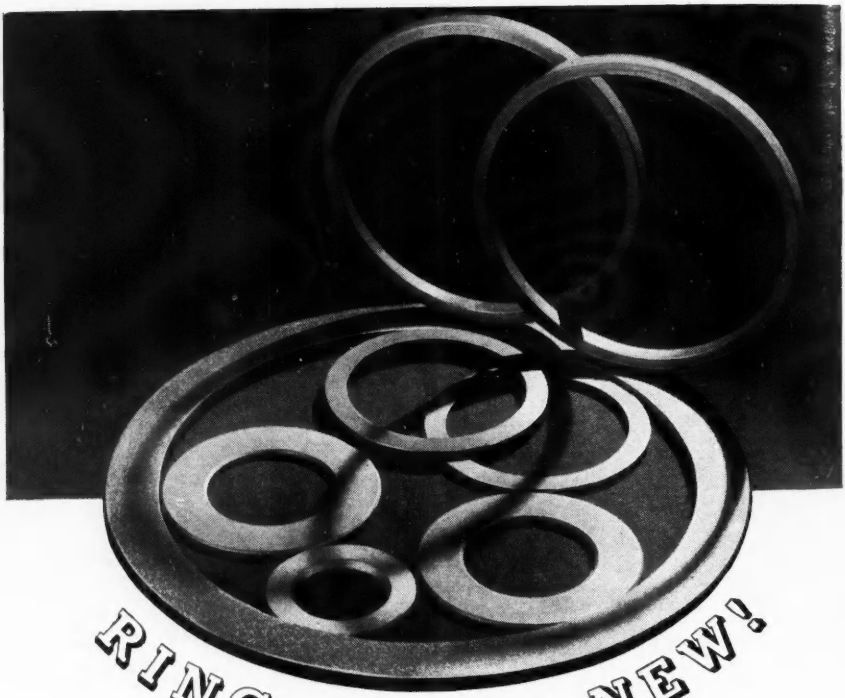


Fig. 2.



RING IN THE NEW!

POWDER METALLURGY offers a new method of making thrust washers, rings, shim plates, discs, etc. They can be mass produced economically in both bronze and iron-copper alloys, with self-lubricating properties. Sizes from ½" O/D up to 10" O/D can be manufactured, according to total surface area. Your enquiries are invited.

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materials for future designs. The shell of each reactor pressure vessel will weigh several hundred tons, and will be subjected to a combination of pressure and temperature never before attained in a vessel of this size. In a battery of 23 G.E.C. vertical heat-treatment furnaces, experiments are being carried out to determine the oxidation and corrosion resistances of steels used in the construction of these vessels. A test-rig has also been set up to examine the effect of creep on the cooling fins of the fuel-element cans.

Fig. 3.

Investigations of heat-transfer characteristics are another important part of the experimental work being undertaken in the heat laboratory (Fig. 3). Measurement of heat-transfer coefficients and friction factors is carried out under conditions of temperature and pressure resembling those in a reactor.

The heat laboratory also contains a number of prototype units, including sections of the charge and discharge equipment and the control-rod operating mechanisms, which are undergoing development tests.

"Plastic Steel" for Joining Metal to Metal

A " plastic steel ", designated " Devcon " and capable of effecting sound metal-to-metal joins in a few seconds, is being marketed by the sole British concessionaires, E.P. Barrus (Concessionaires) Limited, of Acton, London, W.3. Already very well known in the U.S.A., where it is manufactured by the Devcon Corporation, of Danvers, Mass., Devcon, which is a combination of 80% steel and 20% plastic, is stated to be the only known material which will add metal to metal. It can therefore be used to build up worn or broken parts, thereby cutting machinery replacements to a minimum. Thus, for example, it will make a forming die in between 2 and 3 hours, while a holding fixture which might normally take 12 hours to make of steel can be constructed with Devcon in about 15 working minutes, without the aid of machinery.

Originally developed for making inexpensive tools, jigs, fixtures, and moulds in the metal-working industry, Devcon is now used in a wide variety of applications and industries, including ships, electricity plants, aircraft, automobiles, machine tools, and paper and textile mills. Thus, for instance, a giant valve in an American power company was repaired with Devcon in 5 minutes, while a company which had incorrectly machined 400 castings, costing £3500, salvaged them by building them up with Devcon, at a cost of less than £8. Similarly, a 48-in. 3000-ton hydraulic press with three large holes at the base, one of which measured from 15 to 20 in. in length and up to 4 in. in depth, was repaired with a saving of £9000 and 120 days of maintenance time, while a leak in a large water-jacket air compressor in a paper mill was filled in with Devcon, permitting production to be resumed in 3 hours. Further examples include the repairing of a bad leak in the ballast tank of a large collier, of the underwater discharge line of a freighter, and of a boiler blow-down line.

The material is extremely easy to handle and requires no special training. All that is required is to add the special hardening agent (supplied in the exact proportion needed) to the plastic-steel mixture, stir, and then press or pour it into the shape desired. In its unmixed state it will last indefinitely, and when set it becomes a permanently tough and rigid metallic piece. If speed is essential, heat from a blowlamp or infra-red lamp will harden it in seconds. The material is available as a pourable, viscous liquid (Devcon " B ") and in a putty-like form (Devcon " A "), which can be applied to a vertical surface without running or sagging. Both types are alike in that each contains the same proportions of steel and plastic. No inflammable solvents or materials capable of evaporating or deteriorating are used.

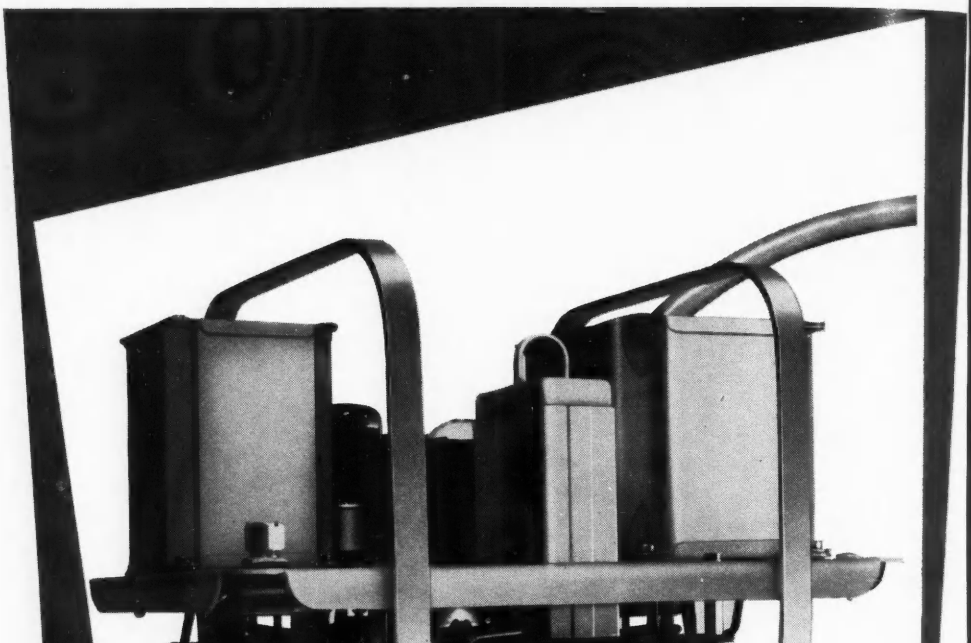
Some of the special qualities and advantages of the new product include excellent resistance to many acids, alkalis, and solvents ; adherence to steel, aluminium, bronze, brass, and cast iron, bonding these materials to themselves and to porcelain, and in some cases to carbides ; high abrasion resistance and high impact resistance ; low shrinkage ; high compression strength (over 18,000 psi) ; and a tensile strength of over 15,000 psi.

Test Equipment for Simulating a Jet-Engine Compressor Tapping at High Altitudes and Supersonic Speeds

In a jet aircraft, the cooling turbines are operated from air tapped from the jet-engine compressor. This tapped air is passed through a ram-air heat exchanger before working the cooling turbine, which supplies cooling air at about 0°C to the cabin and equipment. The temperature, as well as the flow pressure of this tapped air, will naturally vary according to the atmosphere at the flying altitude and the speed of the aircraft, but in a high-speed aircraft will in any case be in excess of 200°C. These differing conditions obviously affect the efficiency of the cooling turbine. To ascertain just what this effect will be, and to gauge the requirements for cooling turbines in a proposed new jet aircraft flying at higher speeds and altitudes, test equipment providing delivery air from a simulated jet-engine compressor tapping has been built in the supersonic-plant area of the Royal Aircraft Establishment, Farnborough.

The first requirement for the simulated jet-engine compressor-tapping equipment was a heater capable of raising the temperature of air passing through it from the delivery temperature of 30°C to something in excess of 200°C. This heater, supplied by The General Electric

Synchronising AUTOMATICALLY



Overall dimensions: 11½" x 8" x 8"

The new Austinlite Synchronising Unit cuts out the need for complex and time-taking precautions when switching the A.C. generator into an already running A.C. system. The Unit detects voltages, phases and frequencies and when these are all in step with the system the generator is safely paralleled and switched in.

More than this, with auxiliary apparatus additional generators can be automatically started up, synchronised, and connected with the system —and later disconnected—as the power demand fluctuates. The Austinlite Synchroniser can again be combined with other apparatus to form a load sharing device between two paralleled generators.

Simple in design, the Austinlite Synchroniser is self-contained, built on a small chassis suitable for back-of-panel mounting. Installation is an easy matter; little or no maintenance is required.

Here, in fact, is another Austinlite answer to a thorny problem of specialised production, another piece of equipment whose owners, years from now, will wonder how they got along without it.

Let us give you a more detailed description of this unit.

Austinlite

ELECTRONIC SYNCHRONISER

STONE-CHANCE LTD.,
(makers of Sumo Pumps and Stone-Chance Lighthouses),
Crawley, Sussex.

Co. Ltd., of London, W.C.2, copes with an air flow of up to 1150 cu ft per minute and withstands a normal working pressure of up to 75 psi. This heater (illustrated), containing some 900 ft of solid-drawn sheathed-wire elements, has a total loading of 180 kW and is encased in a heavy mild-steel 22-in. diameter cylinder of welded construction, which tapers at the exit end to a 6-in. diameter neck. The case is over 6 ft in length, and the air is fed through a 6-in. diameter pipe. Although the air to be heated passes through an oil separator, special precautions have been taken in the design of the heater to meet the possibility of oil from the compressors entering the heater and setting up an explosive mixture of volatilized oil and air. The heater casing has been built to withstand an internal pressure of 150 psi with atmospheric pressure on the outside.

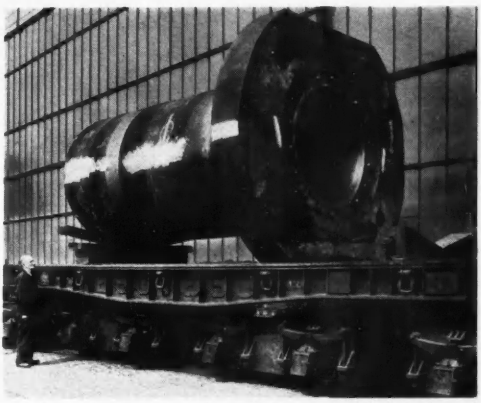
A feature of the heater design is that the elements can be removed without dismantling the entire equipment. These elements are arranged in flat spirals housed within a steel cylinder made up of sections bolted together. Each spiral consists of three elements giving a loading of 5 kW, and six spirals are housed in each section. At the entry end of the heater the inner steel cylinder is welded to a heavy end-plate, to which the outer casing is bolted. When the bolts are removed, the complete heater assembly can be withdrawn from the case. Any section can then be removed individually to give access to the elements it contains. The element terminals are mounted on the outside of the steel cylinder and are connected with insulated cables to a main terminal box at the entry end. To prevent damage to the heater, as a result of overheating in the event of the air supply not being maintained, an excess-temperature thermostat is fitted. The unit is well insulated with asbestos lagging and protected with asbestos waterproof sheeting.

Stainless-Steel Liner for 7000-Ton Forging Press

The machining of a 7-ton stainless-steel liner, 12 ft 6 in. long, with a wall only 2 in. thick and an internal diameter of 5 ft, and its subsequent shrinking into a forging-press cylinder of 7 ft 2 in. outside diameter and 15 ft length, was recently executed successfully by the English Steel Forge and Engineering Corporation Ltd., of Sheffield. To the knowledge of the Company this is also the first occasion on which a large forging-press cylinder has been fitted with a stainless-steel liner to prevent wear from cylinder corrosion of the main hydraulic packings and ram head.

The cylinder, weighing 65 tons, is for the Company's 7000-ton forging press, which is the largest general forging press in the British Commonwealth. Before the liner could be inserted into the cylinder, two other components had to be assembled. The first was a flange, 18¼ in. thick, 12 ft in diameter by 7 ft 4 in. bore, and weighing 18 tons, with a 1¼-in. buttress thread, which was screwed and shrunk onto the bottom end of the cylinder. Then followed a 10-ton plug, 5 ft in diameter by 3 ft 4 in. in length, which was also inserted at the top end by shrinking. All four components were forgings made by the Company, the cylinder and liner being forged under the 7000-ton press itself. Because of the tendency of the liner to sag during machining, special precautions had to be taken throughout the turning and boring operations. Pre-turned rings, for instance, supported by adjustable split spiders, were inserted to support the wall internally during each stage of turning and boring, whilst plugs were also inserted at both ends during turning. On final inspection, the bore of the liner was truly concentric to the exterior.

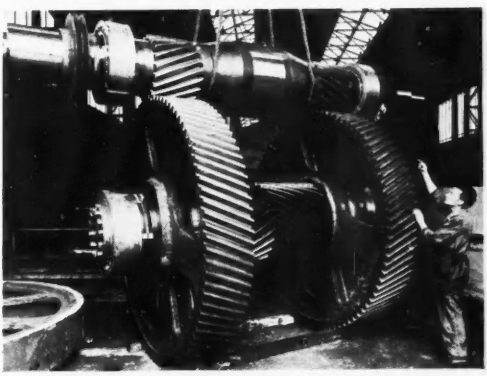
Assembling the various components also called for careful organization and planning. This was due to the necessity for heating the flange in a plate-treatment furnace, half a mile by rail from the scene of the building operation, whilst at a later stage, even after enlarging the



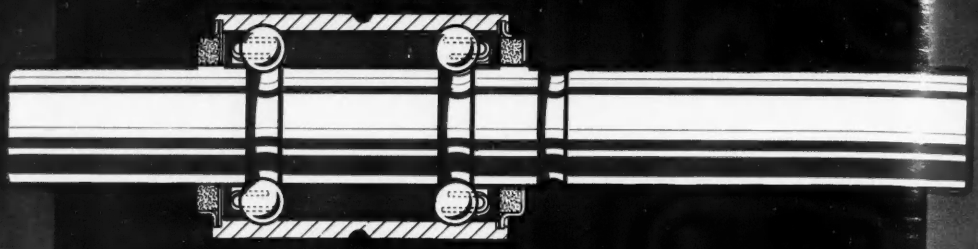
building pit to receive the cylinder, only a few inches of clearance were available from the hook of the 150-ton overhead crane. To shrink in the other components, the cylinder, standing upright in the building pit, was first heated by gas for four days. The flange plug, weighing 10½ tons, was then lowered into position. This was immediately followed by the stainless-steel liner, the bottom 6¼ in. of which had to be registered in a groove formed by the expanded wall of the cylinder and the protruding 6¼ in. of the head of the plug. The whole operation lasted only twenty minutes.

35-Ton Gearing for a Steelworks

As part of the drive to the broadside mill stand in the roughing section of a hot-strip mill at The Steel Company of Wales, Abbey Works, Port Talbot, the Jackson Division of David Brown Industries Limited has recently supplied the 35-ton set of gears illustrated. The two wheels, each with a 16-in. helical face, have 90 teeth of 1 D.P. and are mounted on a forged-steel first-motion shaft. This drives the stand through 24 double-helical teeth of ¾ D.P. on a 57-in. face. Mounted above the wheels is the motor extension shaft, with two sets of 20 teeth and provision for mounting on each end a flywheel, 12 ft in diameter. Forged-steel sleeves, oil slingers, and spacers were also fitted by the David Brown company.



Work rolls in this mill stand are 42 in. in diameter and 130 in. in length, with back-up rolls 54 in. in diameter. The mill is used for normal single-pass reductions and for cross-rolling slabs up to 74 in. wide for rolling into sheets and plates. Power is provided by a 3500-hp motor at 495 rpm, and the drive to the mill is reduced by a ratio of 25·86 : 1 by a gearbox in which this set forms part of the train.



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CLASSIFIED ABSTRACTS

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BRITTLE FRACTURE

The Significance of Charpy Tests for Quenched and Tempered Steels.

By P. P. PUZAK and W. S. PELLINI. (From *The Welding Journal, U.S.A.*, Vol. 35, No. 6, June 1956, pp. 275s–290s, 19 illustrations.)

THE brittle fractures occurring in wartime merchant ships and other large welded structures have resulted in extensive investigations of the factors which contribute to such failures. It is now recognized that brittle failure is a function of various probabilities related to the notch-ductility properties of the steel, the presence of sharp flaws, the service temperature, design features, and loading conditions.

This paper describes crack-starter tests on various high-strength steels, conducted to determine the critical fracture transition temperatures at which welded structures, loaded in the presence of sharp, crack-like defects, may initiate or propagate brittle fractures. The test procedures establish three critical fracture transition temperatures related to the specific loading conditions required to initiate and propagate brittle fractures. The temperature interval of change from the state of complete ductility (even under conditions of severe plastic deformation) to zero ductility (such that brittle-fracture initiation is possible upon reaching incipient yielding in the vicinity of crack defects) is shown to be approximately 100°F for all the steels investigated. This interval was determined to be in the — 200 to — 100°F range for the steels of highest notch ductility, and in the +100 to +200°F range for the steels of lowest notch ductility.

Correlation studies of Charpy V and keyhole transition curves are also presented, and it is concluded that keyhole curves deviate greatly from Charpy V curves for materials of this type. The zero-ductility transition temperature in high-strength steels is generally related to the 20 to 30 ft-lb temperatures of the Charpy V energy-transition curve. Fracture propagation is possible through elastic-loaded material to temperatures corresponding to relatively high positions on the Charpy V transition curve; however, complete resistance to brittle fracture (shear tearing only) is obtained at temperatures related to the "upper shelf" of the curve. In addition, a discussion is presented relative to the use of the critical-fracture transition concept in design.

CORROSION

Inhibiting the Corrosion of Steel, Aluminium, and Magnesium Intermittently Exposed to Brines.

By G. E. BEST and J. W. MCGREW. (From *Corrosion, U.S.A.*, Vol. 12, No. 6, June 1956, pp. 42–48, 14 illustrations.)

THE effectiveness of chromates for preventing metallic corrosion in a wide variety of aqueous media is becoming well known, and their use in sodium and calcium chloride refrigerating brines represents one of the first instances of the use of chemical inhibitors to come into recognized practice. For the most part, however, both experimental and practical inhibitor applications have involved virtually continual contact between the metal and the liquid exposure medium. Under such a condition a reserve of inhibitor is always available for delivery to the metal-liquid interface.

Inhibitors also have received some attention for purposes where exposure is intermittent. Thus, chromates have been effective in mitigating corrosion of automotive equipment by de-icing salt and in reducing the severity of attack of stainless-steel dyeing equipment by hot chloride solution. Furthermore, they have been considered on the basis of favourable experimental evidence for preventing aircraft corrosion by de-icing salts, for minimizing internal corrosion in tankers, and for overcoming the harmful effects of refrigerator-car brine drippings on both rolling stock and track.

The purpose of the present investigation was to obtain experimental information about the ability of chromates to inhibit the corrosive action of sodium and calcium chloride brines under a condition of intermittent exposure. For this purpose, a rotary corrosion tester was devised for cyclically exposing small metal panels, so that they were immersed about one-quarter of the time, drying one-quarter of the time, and dry (in appearance) one-half the time. Tests were carried out using sodium and calcium chloride brines ranging from 1 to 25% concentration with a cycle period of one hour, the duration of testing being 15 days. The influence of chromates and of bichromates on corrosion rate was determined, the use of these two materials serving as a simple means of testing hexavalent chromium at different pH levels, with the chromates yielding higher pH values than the bichromates. The data are intended to indicate orders of magnitude and serve for comparison purposes rather than to provide precisely determined corrosion rates.

The results obtained under these test conditions establish that chromates effectively minimize brine corrosion of mild steel and of selected aluminium and magnesium alloys intermittently exposed to brines at ordinary temperatures. The importance of the ratio between metal surface area and the volume of the test solution is brought out, as is also the effect of pH through comparison of chromates with bichromates. Roughly quantitative indications of inhibitor consumption are also reported.

CRYSTALLOGRAPHY

Plastic Deformation of Germanium in Compression.

By J. R. PATEL and B. H. ALEXANDER. (From *Acta Metallurgica, U.S.A.*, Vol. 4, No. 4, July 1956, pp. 385–395, 15 illustrations.)

LITTLE was known about the deformation of crystals with a diamond-cubic lattice until the work of Gallagher and of Graf and his co-workers demonstrated the remarkable extent to which germanium and silicon can be plastically deformed at elevated temperatures. Indeed, the extremely brittle behaviour of these covalently bonded materials at room temperature provides no indication of their excellent plastic properties at high temperature. Both these elements possess the diamond-cubic type of lattice, which can be visualized as two interpenetrating face-centered cubic lattices. It is reasonable, therefore, to expect that the geometry of slip in germanium should resemble that in face-centered cubic metals. It has been determined that plastic deformation in germanium occurs above 400°C by glide on [111] planes. More recently, the slip direction has been found to be [110]. As in the case of face-centered metals, straight well-developed slip bands can be observed on suitably prepared surfaces of deformed gemanium.

In this paper, the effects of temperature, orientation, impurity content, and annealing on the compressive stress-strain characteristics of germanium single crystals are described, and the following conclusions are drawn:— (1) In compressing germanium single crystals at high temperature, the strain-hardening coefficient decreases

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The control station is now placed so that all the controls face the operator making them more accessible and easier to manipulate. It is connected to the hopper making a single unit which is now hinged, on the weldinghead, thus making accessibility to the wire feed mechanism a very speedy operation.

ALWAYS IN THE LEAD Lincoln Electric have made improvements to their 'Lincolnweld' submerged-arc welding equipment which will cut costs, speed production and produce a better quality weld.

The new 'Lincolnweld' is specially strengthened to avoid whip. Additional idlers and wider rollers are fitted on the travel carriage to ensure lateral stability and freer movement. A double slide is fixed to the strengthened travel carriage which allows vertical movement up and down of 6" and horizontal movement through 4½". The wire feed gear-box, control-box and hopper can be rotated through 90° to cope with circumferential seams.

A new feature is the adjustable spot light which helps the operator to see the point of welding. The arrowpoint light is operated from 115V DC at 12V through a variable resistor—the power going through the welding unit and not requiring any additional outside current supply.

The new position of the wire reel carrying stand gives better weight distribution and improves the feeding to the drive rolls and welding nozzle. A special hand adjusted wire straightener ensures that the wire is straight as it leaves the nozzle. The rollers are suitable for either single or twin arc welding.

On the flux hopper a Flap valve replaces the quadrant valve enabling solenoid control to be applied to the flux feed. The new nozzle design is streamlined and circular in section. Two types can be fitted, type A. is suitable for Lincolnweld wire $\frac{5}{64}$" to $\frac{1}{8}$", type B. for Lincolnweld wire $\frac{3}{32}$" to $\frac{7}{32}$". A flux retainer can be fitted round the nozzle to ensure the retention of the correct volume of flux at the welding point

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very rapidly as the temperature is increased, but does not tend to zero as the melting point is approached. The extremely sharp rise in the strain-hardening curve of germanium at lower temperatures indicates that enormously high stresses would be required to initiate glide in these crystals at room temperature, and most likely fracture would occur first.

(2) The orientation-dependence of the stress-strain curves is similar to that observed for metals. The [111] orientation hardens the most, followed by the [100] and [110] orientations.

(3) For polycrystalline germanium, the stress-strain curve is observed to lie between the extreme compression curves of single crystals of different orientation. The same behaviour is observed in tension in polycrystalline cubic metals.

(4) Annealing a previously compressed sample for 30 min at 800°C shows a very slight decrease in dislocation density. On heating for much longer times and at a higher temperature (16 hr at 900°C), more significant changes are observed. The density of dislocations decreases by a factor of 5, and the straight rows of etch pits falling along slip lines become curved after annealing.

(5) Increasing the impurity concentration by a factor of 700 over an initial impurity content of $1 \times 10^{-7}\%$ does not seem to affect the stress-strain behaviour at elevated temperature.

(6) For orientations near the [100]–[111] and [111]–[110] boundaries, slip takes place on planes of the primary and critical type from almost the beginning of deformation, even though the specimens are orientated in a region favouring single slip.

(7) Dislocations have been shown to lie along slip lines in germanium. The linear dislocation density obtained by counting etch pits along a slip line has proved to be an order of magnitude lower than the calculated value.

(8) Dislocation density has been determined as a function of strain by direct visual examination. Initially, the density ρ increases by three orders of magnitude from $5 \times 10^3/cm^2$ to $2 \times 10^6/cm^2$ for a strain of 1%. A plot of $d\rho/d\varepsilon$ against ε shows that, $d\rho/d\varepsilon$ passes through a maximum between 2 to 3% strain.

ELECTROPLATING

The Electrode Process in Metal Deposition from Aqueous Solutions.

By E. MATTSON. (From *Acta Polytechnica, Sweden*, No. 184, 1955, 56 pages, 14 illustrations.)

In this paper, the ion exchange through the interface is considered for a piece of metal immersed in a solution containing ions of the same metal. The energy barrier for ion discharge and ionization at the interface is constructed by superposition of two potential energy curves, one representative of ion extraction from the solution and the other of ion extraction from the metal. The conception of electrode potential is explained and a relation derived expressing it as a function of the ion activities in the metal and solution. The structure of the electric double layer, built up at the interface, is also discussed.

The mechanism of the deposition process is presented as a combination of the ideas in literature concerning the different reaction steps. Owing to obstructions to the deposition process, an electric activation of the metal ions in the solution is necessary for the reaction to proceed at a finite rate. This activation is equivalent to a reduction of the electrode potential and is called polarization. Three types of polarization are distinguished, i.e., concentration, ohmic, and activation polarization. For each type, a relation has been derived expressing it as a function of the current density. The contribution of the different types to the total polarization is discussed.

A convenient way of drawing the polarization/current-density curves is recommended and methods for the determination of the exchange current density, the characteristic constant, and the polarizability, using the polarization curve, are described.

The magnitude of the activation polarization depends on the nature of both the metal and the interface region. Thus, according to Piontelli, normal, intermediate, and inert metals are distinguished by their low, medium, and high activation polarizations. These differences are supposed to originate from differences in the nature of the metal bond. In the interface region, inhibitors may block active centres on the electrode surface and thus increase activation polarization. The structure of the interface region is also influenced by the anions in the solution. Four theories are presented, which try to explain the influence of the anions on the polarization.

When the electrolysing current is switched on, the ohmic, activation, and concentration polarizations are fully built up within 10^{-5}, 1, and a few seconds respectively. The slower variations may depend on slow changes in the electrode structure during the electrolysis or on slow adsorption of inhibitors. From the temperature influence on the polarization, the free energy of activation for the deposition process can be calculated with the aid of the general rate equation.

FATIGUE OF METALS

The Problem of Fatigue Strength in Aircraft Structures.

By E. GASSNER. (From *Aircraft Engineering, London*, Vol. 28, No. 329, July 1956, pp. 228–234, 11 illustrations.)

In aircraft construction, until about fifteen years ago, the customary static method of stressing generally also provided for an adequate fatigue strength. This does not now apply, for reasons such as increased flight speeds and the use of materials which do not show a commensurate increase in fatigue strength.

Economic considerations of modern airliner and freight-aircraft operation are based on a service life of 30,000 to 50,000 flight hours per aircraft. This value represents a three to fivefold increase over the corresponding figure valid twenty years ago. However, it is more appropriate to take the distance flown as a basis for such comparisons, because the number of gust loads encountered is proportional to the distance, and it is essentially the gust loading which determines the fatigue life of commercial-aircraft structures. If this is done, and the increase in speed over the past twenty years is taken into account, the distance flown to-day is nine to fifteen times greater than it was then. Consequently, strength requirements should be amended in accordance with the more recent knowledge on fatigue strength discussed in this paper. By means of fatigue tests which, to a considerable extent, cater for the peculiar loading conditions of flight (service endurance tests or programme-loading tests) it has been proved that the static method of stressing, hitherto in general use for tension members of the wing, does not provide for lives now required.

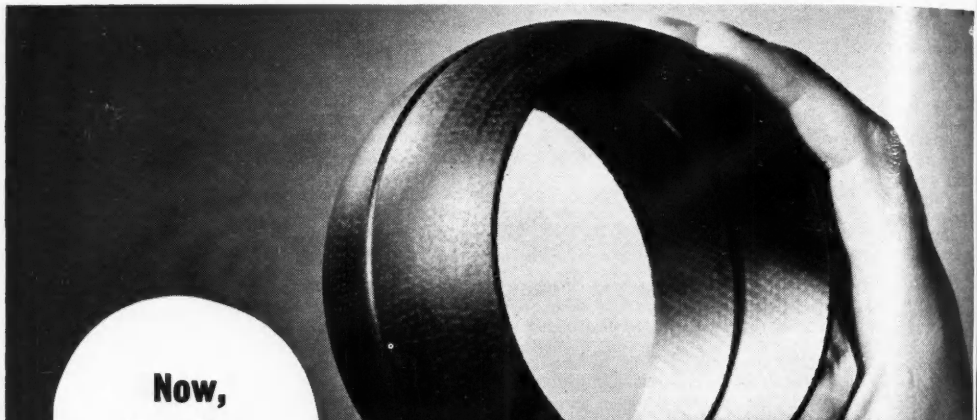
The stresses resulting from the static method of stressing are replaced by those found from service endurance tests. The latter " characteristic " stresses are defined by the maximum stress (mean stress plus stress amplitude) in a given type of load spectrum, the application of which is just sufficient to lead to failure. Tests of this kind have been made on typical wing members, and the effect of various materials and load factors on life investigated. A design diagram is presented, and an example is given to illustrate the recommendations for rules on wing-member specimens of the same design and type of alloy, but with different ultimate tensile strengths.

INSULATING MATERIALS

The Ageing of Insulation in the Stators of High-Voltage Generators.

By J. HASSDENTEUFEL. (From *Elektrotechnicky Obzor, Czechoslovakia*, Vol. 44, No. 12, December 1955, pp. 617–622, 9 illustrations.)

One of the most important sources of trouble in high-voltage rotating machinery is faulty insulation in the stator. The requirements of such insulation include



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homogeneity, adequate electrical and mechanical strength, thermal stability, and good thermal conductivity. The electrical breakdown voltage should be from 6 to 7 times higher than the nominal voltage. Furthermore, it is essential during manufacture to prevent the formation of cavities in the insulation. Thermal stability depends mainly on the bonding materials, which are at present the subject of development, with a view to improving their performance at elevated temperatures.

The insulation is mechanically stressed during manufacture and subsequently during operation as a result of vibration produced by cyclic magnetization and sudden load changes, especially short-circuits. Differences in the thermal coefficients of expansion of the metals used and the insulation give rise to thermal stresses, causing deformation of the insulation and the formation of cavities. Ageing of the insulation is caused by electrical discharges through the cavities, coupled with the influence of elevated temperatures. Such discharges are particularly dangerous where the conductors leave the slots, but fortunately these can be suppressed by applying a suitable semi-conductive material to the winding surfaces at the slot exits.

This paper describes the results of tests on the progress of ageing of the insulation of more than one hundred generators. The loss angles for voltages up to 150% nominal phase voltage were measured at regular time intervals, and the generators were classified with regard to the quality of their insulation on the basis of these results. The loss-angle measurements were carried out on a Schering bridge with an external source of energy. The influence of the end windings on dielectric losses was also investigated theoretically and experimentally and was found to increase these losses by about 10% only. Measurements of insulation resistance agreed qualitatively with the loss-angle measurements.

In addition, direct-current voltage characteristics were obtained for machines no longer in service and, as expected, it was found that resistance decreased with voltage, though electrical breakdowns occurred without any indication of their imminence in the characteristics. For this reason, this particular test is not recommended, and it is suggested that it would be desirable to develop methods capable of detecting the weakest points in insulation, as at present no single test can lead to a satisfactory prediction of the imminence of breakdown.

RECTIFIERS

Test and Operating Experience with the Triple-Diametric Rectifier.

By R. V. WACHTER, C. S. HAGUE, and C. R. MARCUM. (From *Applications and Industry* (*A.I.E.E.*), *U.S.A.*, No. 24, pp. 100–106, 10 illustrations.)

DURING the last twenty years, the design and application of mercury-arc rectifiers in the U.S.A. have undergone radical changes, the single-anode designs having completely outmoded the multi-anode designs. The aluminium industry with its rapid growth has required larger and larger blocks of d.c. power. Over the last decade, the rating of a single rectifier unit has been increased by 60%, while, at the same time, the size of single loads in the aluminium industry has increased 150%. With single loads of 100,000 kW supplied by parallel rectifier units, there can be no question regarding the need for increased ratings of rectifier units. This paper describes a practical re-examination of a discarded idea, the triple-diametric circuit, in the light of interim developments.

Because fundamental equations indicate certain important practical advantages for the triple-diametric circuit, particularly when used with single-anode rectifier tubes, laboratory and field experiments on equipment utilizing this circuit have been made to evaluate its performance. These experiments have shown the following important characteristics of the circuit, as compared with conventional double-wye operation:—

(1) It is practical to build an effective 3-phase interphase transformer to enforce 180-deg. tube conduction.
(2) Direct-current contribution to arc-back current is greatly reduced for the initial period between the instant of arc-back and the time in which high-speed anode circuit-breakers effectively limit fault current.
(3) Higher per-unit forward currents in the diametrically connected anode may cause an increase in the incidence of sympathetic arc-back.
(4) Tube arc voltage for a given average current is reduced.
(5) Where tube ratings are normally limited by arc-back rate, average tube current can be appreciably increased without sacrifice in performance.

Although the circuit has some detrimental characteristics, these are not serious, and its advantages for certain applications far outweigh the disadvantages. In general, the application of the circuit on large installations in electrochemical service will enable the accomplishment of a given d.c. bus rating with fewer rectifier assemblies and associated equipment. This will result in smaller building space requirements, and reduced installation and maintenance costs. Because of these advantages and because of the reduction in magnitude of the arc-back current, which is a characteristic of this mode of operation, equipment utilizing this circuit is now being manufactured to furnish d.c. power for three large electrochemical installations totalling over 200,000 A.

WELDING

Properties of Arc-Welded Joints between Aluminium and Stainless Steel.

By M. A. MILLER and E. W. MASON. (From *The Welding Journal, U.S.A.*, Vol. 35, No. 7, July 1956, pp. 323s–328s, 13 illustrations.)

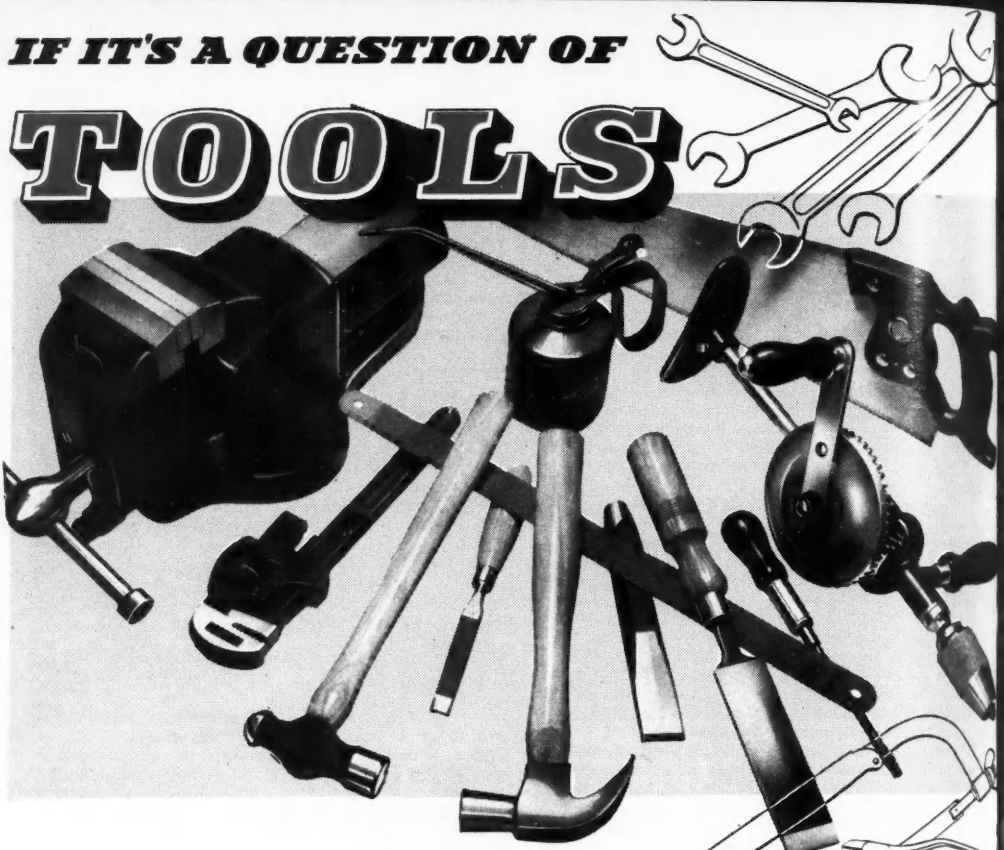
A NUMBER of aluminium alloys can be tungsten-arc-welded to aluminium-coated stainless steel, with or without added filler metal, provided that the welding is effected in such a way that the arc "favours" the aluminium portion of the assembly. This permits wetting and metal flow over the aluminium coating, without shattering or increasing the thickness of the iron-aluminium compound interfacial layer.

This paper describes the proper method of joint preparation and design, and summarizes available data on the performance of metallurgically bonded aluminium-steel joints. Particular attention is directed to inert-gas-shielded tungsten-arc-welded joints between aluminium and aluminium-coated stainless-steel tubes.

The effect of post-heating on the shear strength of aluminium-steel joints made in various ways indicates that welded tube joints might operate safely at temperatures up to 500°F for long periods of time without serious loss of shear strength. Thermal-shock cycling tests between room temperature and 500°F on brazed aluminium/type 347 stainless-steel joints suggest that arc-welded joints between aluminium and stainless-steel tubes will be able to withstand this type of treatment without damaging effect. Available data indicate that aluminium tube/stainless-steel tube joints will have an adequate resistance to corrosion in many environments.

Argon-shielded tungsten-arc-welded joints between aluminium alloys and aluminium-coated stainless steel have satisfactory mechanical properties. When properly made, welded joints can be sound and vacuum-tight. The shear strength of arc-welded aluminium-steel joints is of the same order of magnitude as the shear strength of aluminium-steel joints made in other ways. Based on published information on aluminium-steel joints made in other ways, it can be expected that the shear strength of arc-welded aluminium-steel joints may not be too adversely affected by long exposures to temperatures below about 500°F. Furthermore, aluminium-steel joints can withstand cyclic thermal shock between at least 500°F and room temperature, and the resistance to corrosion of tungsten-arc-welded aluminium-steel joints is adequate in all except the most severe environments.

IF IT'S A QUESTION OF TOOLS



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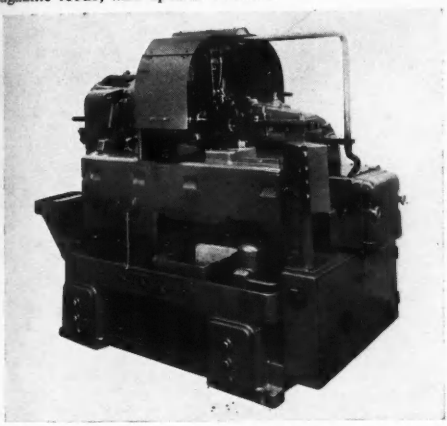
New Materials, Processes, and Equipment

SINGLE-SPINDLE AUTOMATIC TURRET LATHE

Manufactured by Tarex Ltd., in Geneva, Switzerland, and distributed in the United Kingdom by Tarex (England) Ltd., of London, S.W.1, the new single-spindle automatic turret lathe, model TAR-L, is a machine which is basically very simple, sturdy, and accurate. Nevertheless, it is essentially versatile and, where workpieces are complex or require several operations during the same chucking, its possibilities may at any time be extended by a range of standard units which can be fitted, as required, to the basic machine. These units, which take the form of various attachments and standard and special accessories, include a single-point thread-chasing attachment, a swing-stop, a high-speed drilling attachment with single or multiple heads, a spindle brake with positioning device, magazine feeds, and special chucks.



Three alternatives are provided for the headstock, which therefore may comprise either two spindles designed solely for bar work, or a universal spindle for bar and chuck work. Thus, models TAR-L/32B and TAR-L/52B, with maximum spindle speeds of 4730 and 2545 rpm and maximum capacities of 1¼ and 2 in. diameter respectively, are intended exclusively for bar work. On the other hand, model TAR-L/42 (illustrated), with a maximum spindle speed of 2945 rpm, has a maximum capacity of 1⅜ in. diameter for bar work or 4⅛ in. diameter for chuck work, the maximum machining diameter being 6 in. In all these versions, pick-off gears provide two automatic spindle speeds, in the same or opposite directions. High speed can be either right- or left-hand.

GLASS-FIBRE BONDING TAPE

Affording high tensile, mechanical, and impact strength, the "Varband" bonding tape announced by the Varflex Corporation, of Rome, New York, has excellent dielectric qualities and high thermal stability with no distortion or elongation. In addition, the tape has great resistance to mild acids, alkalis, oil, and grease, and there is neither interference with magnetic fields nor danger of arc-over.

Composed of hundreds of parallel glass-fibre yarns, uniformly coated and impregnated with a special polyester resin, the new tape bonds and protects wires permanently and can be used as a structural component to replace banding wire and for coil windings and tying support... The tape may be wound around wires as with ordinary tape, and the end can be heat-sealed by a soldering iron, eliminating knots. The material readily lends itself to knotting and tying, where desired. Armature banding, core and stator winding, and coil tying supports are but a few of the many industrial applications for which Varband bonding tape is recommended. It is particularly suitable for anchoring wires in vibrating power tools, or wire assemblies rotating at high speeds.

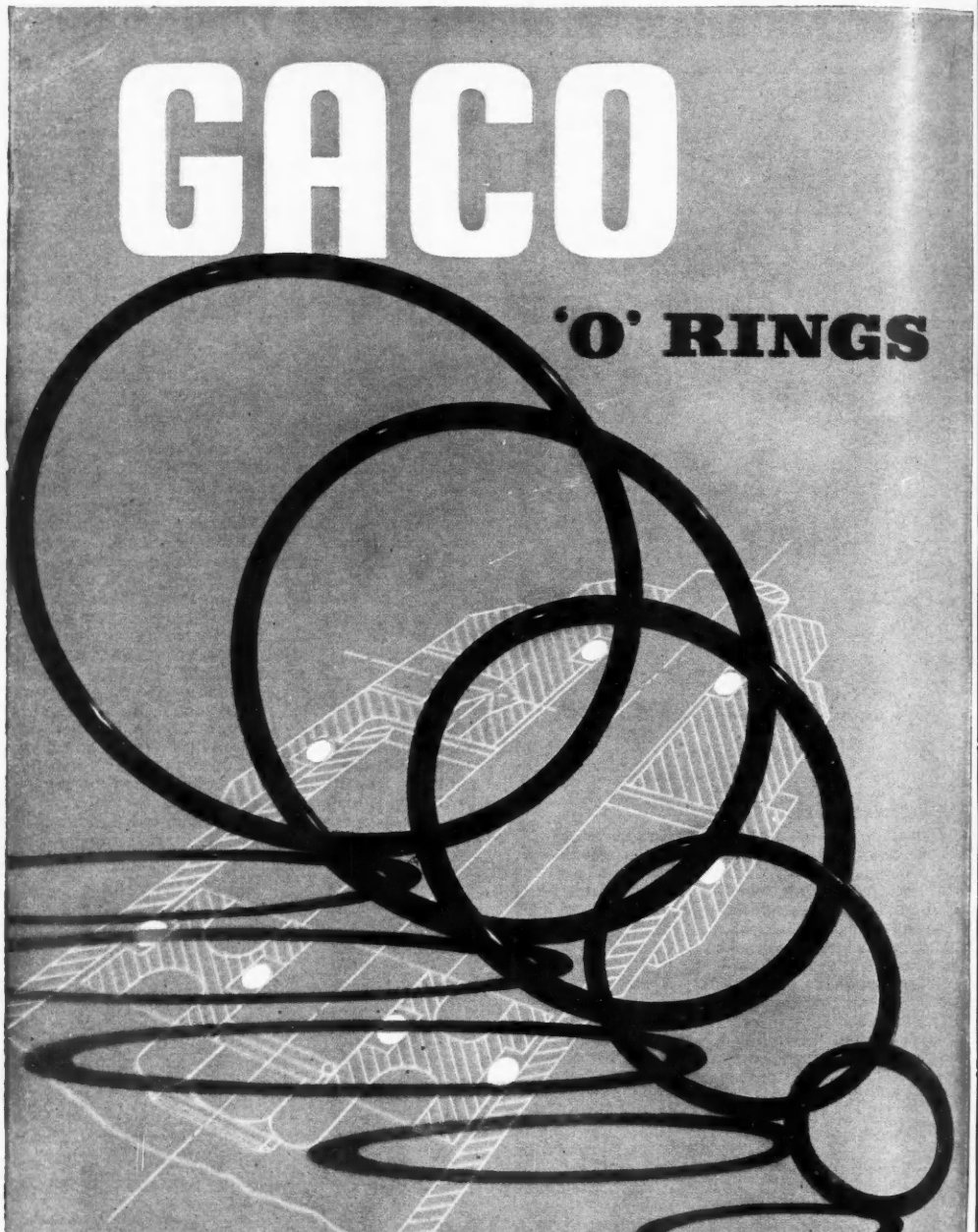
When cured, the tape becomes a homogeneous, machinable mass which is impregnated not just on the surface but all the way through. The recommended curing time is 3 hr at 125°C, or less at higher temperature. At present, there are six standard widths available, ranging from 10 ends to 120 ends, with a thickness of 0·015 to 0·030 in.

HIGH-PRODUCTION GUN FOR MILLSCALE REMOVAL

The new "Vacu-Blast" high-production gun announced by Vacu-Blast Limited, of Slough, Bucks., has been specially designed to obtain a high rate of millscale removal from flat horizontal plate, prior to fabrication. The gun can be operated manually, or alternatively a motorized version (illustrated below), self-propelled by means of a variable-speed carriage, can be supplied. A blast-cleaned track, 8 in. in width, is obtained with each pass of the gun, and millscale can be removed at an average rate of between 300 and 600 sq ft per hour, depending on the condition of the surface to be blasted.

In effect, the gun, which is intended for use in conjunction with the Vacu-Blast "Senior" machine, takes the form of a small blast cabinet, in which is fitted a rotating nozzle assembly consisting of three ¼-in. blast nozzles. Abrasive is directed through these nozzles onto the work surface with great force and, as soon as the abrasive has done its work, vacuum pick-up returns it, together with the surface deposits removed, to the "Senior" machine, where the abrasive is separated from the debris and then returned automatically and continuously to the gun.

The Vacu-Blast "Senior" model 260L CC (illustrated overleaf) is a continuously cycling, mobile shot-blast machine designed for use with chilled cast-iron abrasive.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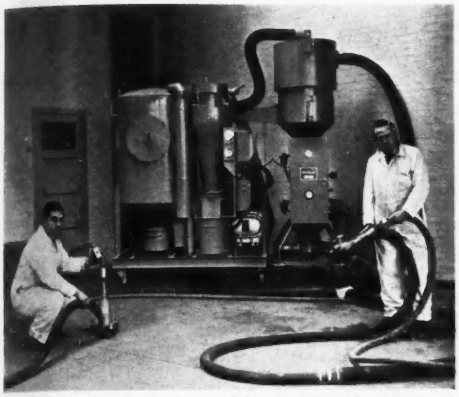
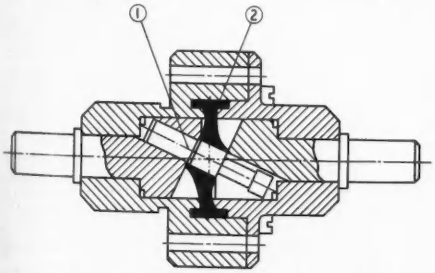


It consists of a generator-reclaimer unit and a dust collector fitted with a 25-hp electric motor, and requires 260 cfm of clean dry air compressed to about 100 psi. The dust-collector unit and the generator-reclaimer unit may, if desired, be combined to form a single integrated unit measuring 9 ft 4 in. × 3 ft 6 in. × 9 ft high.

By means of the high-production gun the dust-free Vacu-Blast technique can now be applied to the shot-blasting of large volumes of steel plate in the shop, without endangering health or adjacent equipment and without interfering with nearby operations. Furthermore, owing to the high work output of the gun, the minimum of equipment is required, and the cost of the operation is negligible. Finally, when the high-production gun is not in use with the " Senior " machine, two standard Vacu-Blast guns may be connected to the machine, thereby enabling two operators to accomplish a variety of blasting operations, adding to the versatility of the equipment.

HERMETIC COUPLINGS

Eliminating all the common objections to axial seals, the new range of " Hydro-Pneumatic " hermetic couplings manufactured by Hydro-Pneumatics Ltd., of Egham, Surrey, incorporates a true hermetic seal which withstands positive and negative pressures and which can be fitted equally well to the suction or delivery end of pressurized apparatus.

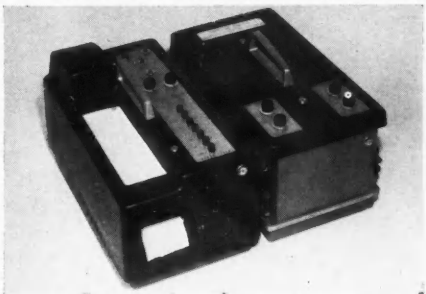


In these new couplings, which have a continuous speed rating of 300 rpm and are suitable for differential pressures up to 30 atm, the driving and driven members are in common alignment with the drive shaft to be sealed and are interconnected by an angular driving pin (1). A flexing member or diaphragm (2) is chemically bonded to the midpoint of this angular pin, and its periphery is securely clamped between the housing and lid forming the coupling case. In operation, the point of intersection of the longitudinal and diametric centres of the pin remains stationary, but the actual point of attachment of the diaphragm to the pin describes an oscillating motion, the degree of which depends on the diameter of the pin and the angle at which it is set between the two shaft ends. The driving shaft of the coupling rotates the pin in a circular conical path around the stationary midpoint, whilst the opposite end of the pin imparts rotation to the driven shaft. The type of diaphragm and its material depend on the fluid to be sealed and the amount of angular displacement given to the pin.

In addition to providing a 100% hermetic seal against positive and negative pressures, the " Hydro-Pneumatic " hermetic coupling has a number of other important advantages. Thus, it is unaffected by the medium contained, it requires no periodic adjustment (as distinct from packing glands, etc.), it can be driven in any rotational direction, and it can easily be removed from the equipment or driving shaft without any ill effects either to itself or to the equipment.

DIRECT-WRITING OSCILLOGRAPH

A new, two-channel, direct-writing oscillograph which provides instantaneous, permanent recordings of frequencies as high as 250 cps at 1-in. double amplitude has been developed by the Consolidated Electrodynamics Corporation, of Pasadena, California. This equipment, consisting of a Type 5-301 " Datagraph " and a Type 1-133 amplifier, shown respectively on the left and the right of the illustration, can record voltages from practically any source, including magnetic-tape playback units, carrier amplifiers, audio amplifiers, d.c. amplifiers, and telemetering discriminators. Almost any input device is suitable because of the high input impedance of the instrument. In addition to a frequency response which is



flat to 250 cps, the Datagraph has excellent square-wave and transient response, and incorporates a new concept in recording data. It employs a vibrating wire in a strong, specially shaped magnetic field provided by a permanent magnet. The wire burns a contact wherever it touches an electro-sensitive paper as it travels over an anvil, providing rectilinear writing. The record may be seen through a viewing window immediately after it is recorded. Since the recording system uses no ink, traces are clean and can be interpreted easily. Speed-change push-buttons select six chart speeds from 0·05 to 20 inches per second, and separate control knobs set the trace density for each of the two channels. Timing pulses are provided automatically at one pulse per second, or up to five pulses per second by external means. A manual " event marker " push-button can be used to mark the chart at any time.

PORTABLE HARDNESS TESTER

An improved model of the " Indentometer ", a portable Rockwell-type hardness tester, has been introduced by C. Tennant, Sons & Co., Ltd., of London, E.C.2. The modifications incorporated are intended to ensure even greater facilities for testing than was possible with previous models, and were made in collaboration with the Citroen Company of France, in order to meet the requirements of their factories.

The Indentometer, which may be used with loads up to 150 kg, gives readings on the Rockwell A, B, or C scales, the load being applied through a hydraulic pressure

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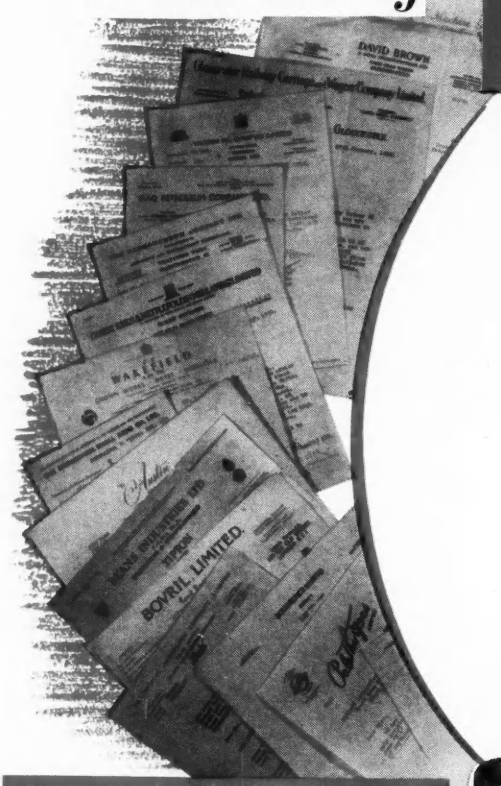

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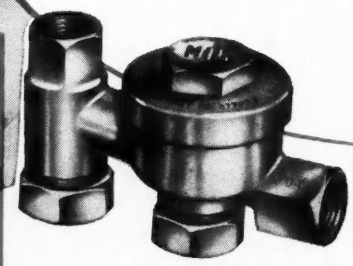

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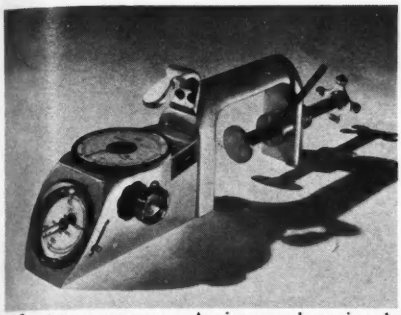
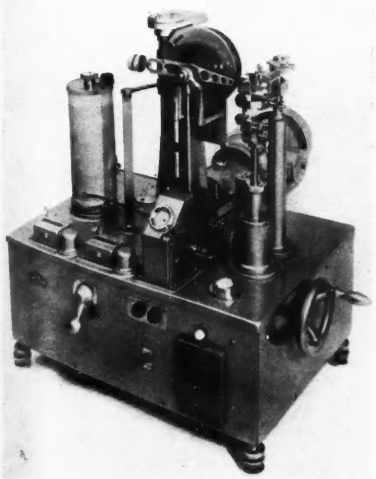


unit of extreme accuracy. An improved zeroing device is now provided, to enable variations in atmospheric conditions to be counteracted under all possible conditions. The provision of a carrying handle at the point of balance of the instrument facilitates handling and testing, while a new method of mounting the penetrator simplifies changing from a conical diamond to a ball. In addition, an improved easily read dial has now been fitted for registering the applied load.

A U-clamp, providing for the testing of pieces up to $\frac{5}{8}$ in. in thickness or diameter, is supplied as standard equipment. A special quick-release cam mechanism can also be provided, if required ; furthermore, a chain type of clamp may be used for testing large or awkwardly shaped specimens, or an electromagnetic clamp for testing ferrous cylinders, rolls, or large flat surfaces. Finally, a new stand has also been introduced, permitting the instrument to be converted for normal bench testing.

INSTRUMENT FOR MEASURING THE STRENGTH AND ELONGATION OF VERY THIN WIRES

With the availability of very thin wires, with diameters as small as 0·01 mm, there is naturally a requirement for an instrument capable of measuring their mechanical properties. Such an instrument has been developed by Karl Frank G.m.b.H., of Weinheim-Birkenau, Germany, and is intended for the accurate determination of the strength and elongation of very thin wires.



This new high-precision instrument is particularly suitable for batch measurements, as, apart from providing a graphical record, it is fitted with two built-in counters which automatically add individual strength and elongation values, giving directly their mean value at the end of the measurements. Thus, considerable work in evaluating graphs is eliminated.

The instrument is designed on the principle of the torsion balance, the spring being connected to the recording gear in such a way that the wire under examination is not affected by extraneous forces. The grip on the wire is 10 mm, and the minimum test length is about 25 mm. The beam is supported on knife-edges and carries the grip on one side and the balance weights on the other. Two measuring ranges are provided, i.e., 0 to 20, and 0 to 200 grams respectively, and the gearing is such that the pointer can traverse a complete measuring range in between 15 and 210 seconds, depending on the rate of load application, which is infinitely variable.

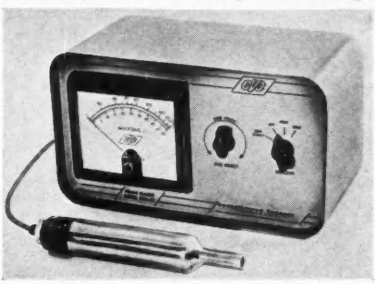
TOROIDAL REGULATORS

The latest addition to the already very wide range of voltage-regulating equipment manufactured by Foster Transformers Ltd., of South Wimbledon, London, S.W.19, is their toroidal regulator, which has been designed to provide a reliable means of obtaining an infinitely variable " on-load " voltage control from zero to maximum. The design of the unit results in a very low magnetizing current, contributing to a high overall efficiency and reducing waveform distortion to a minimum.

The input voltage is 240 or 120 V maximum, with an output current of 3 A from 0 to 250 V, or 2 A from 250 V maximum (on a 240-V supply tap). These new regulators, which are available as open or enclosed types, are $6\frac{3}{4}$ in. in diameter and 8 in. in height (overall, complete with case), and weigh $11\frac{1}{4}$ lb.

SINGLE-STATION PIRANI VACUUM GAUGE

A new, single-station Pirani vacuum gauge, giving direct, continuous pressure readings from 1 to 2000 microns Hg is announced by the Rochester Division of Consolidated Electrodynamics Corporation, of Pasadena, Cal. Designated Type 2201–03, this instrument measures on two scales the total pressure of condensable vapours and permanent gases in a vacuum system. The high-range



The development of the latest technique of oxygen furnace-boosting may well revolutionise steel production in this country. Its successful application has already produced striking economies of up to 20%, and it may have far-reaching effects in speeding up the whole production schedule.

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scale reads from 0 to 2000 microns Hg, 50 microns being the lowest division. The low scale expands the 0- to 50-micron portion of the upper scale and is calibrated in units of one micron.

A new sensing tube greatly reduces zero drift, solving one of the greatest problems in previous hot-wire gauges. Automatic voltage regulation is provided for easier operation and permits the use of a recorder, without constant attention from the operator. Because of its increased sensitivity in the presence of hydrogen or hydrogen-rich gases, the new gauge can be used as a detector of major leaks in vacuum systems. The new gauge, which is 11 × 6 × 6½ in. high and weighs 10 lb, incorporates a printed circuit for compactness, greater operational uniformity, and lower cost.

TRANSISTORIZED ELECTRONIC MEGAPHONE

Weighing only 5 lb and having an effective range of over 400 yards, the new "Transhailer" completely transistorized electronic megaphone developed by Pye Telecommunications, of Cambridge, is specifically designed for speech across distances or against background noises; as such, it is therefore especially suitable for use in ships, marshalling yards, factories, sports arenas, etc.

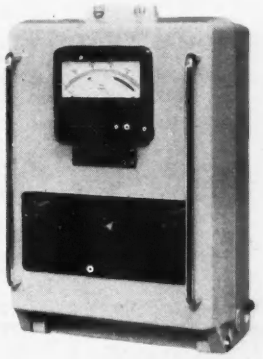
Claimed to be the first all-transistor loudhailer, and certainly the lightest electronic type ever produced, the new megaphone is operated by standard torch-batteries, and combines portability and exceptionally good speech quality with long battery life, which, based on an average use of 10 seconds per minute, should reach six months.

Basically, the "Transhailer" is a fully self-contained power megaphone consisting of a high-efficiency folded-horn loudspeaker, a 3-W germanium transistor amplifier, a sensitive electromagnetic microphone, and batteries, the whole being assembled in one splashproof unit, complete with handle and trigger-switch. The amplifier will operate satisfactorily at temperatures ranging from −20 to +45°C, average consumption on speech being 120 mA. The power output for 10% distortion is 3 W, with a maximum output of 3½ W. Frequency response is flat within 3 decibels in the range of 200 to 4000 cps.

NUCLEONIC LEVEL INDICATOR

A new nucleonic level indicator, designed to overcome many of the shortcomings of existing equipment by making use of gamma radiation, is announced by the Baldwin Instrument Co. Ltd., of Dartford, Kent. In this indicator, a gamma-emitting isotope is placed on one side of a container and a detector on the other. Radiation passes from the isotope, through the container to the detector, which is, in fact, a Geiger counter. The output from the detector is proportional to the amount of radiation which it receives. In practice, then, when the contents of a container are below the radioactive "beam", maximum radiation will be received by the detector. When the contents rise and cut the beam, the radiation reaching the detector will be substantially smaller. The difference in radiation reaching the detector is shown as a difference in electrical output from the Geiger counter, and this is arranged to operate a relay. The indicator unit shown in the illustration houses the relay and two lamps which indicate whether the beam is broken or not. It is a relatively simple matter to incorporate the relay in some automatic control circuit. For complete control, two heads can be fitted to the container, thereby giving indication when the contents reach both maximum and minimum levels. Alternatively, a movable head can be fitted, so that the level can be determined at any given time. As the operation of the relay is dependent in the first instance on the difference in radiation, it is possible to detect the boundary between, say, two liquids having substantially different densities. This is simply because the lower the density, the greater will be the amount of radiation which will pass through.

The great advantage of the instrument is that nothing needs to be inserted in the container, both the isotope and the detector being simply mounted on the outside. This



is obviously of great importance in installations involving control of corrosive liquids, materials at very high temperatures, liquid gases in pressurized vessels, etc. Furthermore, considerable care has gone into the design and manufacture of this instrument to ensure the highest possible degree of reliability. The electrical components have been chosen and the circuit specially designed to give maximum trouble-free service, while the equipment in both the detector and the indicator unit are housed in robust dustproof metal cases and are installed on anti-vibration mountings.

The Behaviour of Transistors at High Current Densities

(Concluded from page 381)

gallium in germanium. Favourable results have indeed been achieved by this process, as appears from Fig. 3, in which 1—α is plotted as a function of the emitter current I_e in an experimental transistor built on this principle.

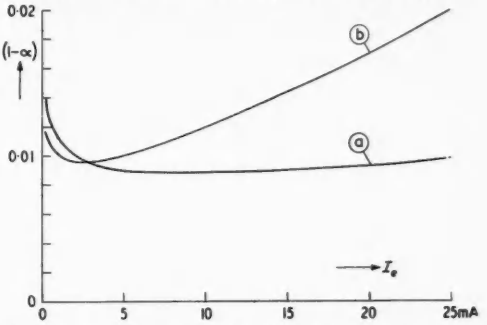


Fig. 3. Transistor losses as a function of emitter current for transistors containing, in addition to indium, (a) gallium, and (b) no gallium.

A higher equilibrium concentration of majority charge carriers in the emitter is a particularly attractive feature in power transistors, in which current densities are always high, but the process can also be profitably applied in the manufacture of transistors not intended for high current densities. Raising p_{P0} allows n_{N0} to be raised while keeping the same values for B and hence for 1—γ. This means that a base material of higher conductivity can be chosen, and this is of advantage for limiting the influence of the "Early effect"[1]. The same principle can also be applied in the manufacture of transistors for high frequencies.

CARBORUNDUM LEADS AGAIN!

FASTER, SMOOTHER FINISHES WITH THE

FLEXBAC

PAD

No gouging, no swirl marks, with the 'Flexbac' pad, and on many operations the sanding time can be *cut to one-eighth!* Now introduced in this country by CARBORUNDUM, the 'Flexbac' pad consists of a foam-rubber cushion on which an abrasive disc is mounted merely by pressing it into position. When the abrasive is worn, the used disc is peeled off and a new one pressed into position within seconds.

'Flexbac' pads are speeding and improving surface finishes in a wide range of industries. The unique flexibility of the pad enables the abrasive to explore contours and radii which ordinarily waste hours of tedious hand-work with shaped sanding blocks. Motor bodies, moulds for television tubes, formers and moulds for aircraft construction, and other highly finished products, are all sanded better and in a fraction of the time with 'Flexbac' pads. In boat building, the 'Flexbac' pad moulds itself to complex curves and provides beautiful finishes quickly, without tearing the caulking. You must try the 'Flexbac' pads yourself! Write for a demonstration.

In motor body finishing, 'Flexbac' pads are used for smoothing primers, fillers, and undercoats

FLEXBAC

PAD

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Abrasive products by **CARBORUNDUM**

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NEWS OF THE MONTH

PERSONAL

Mr. W. Duckett has been appointed General Manager of Martin Thomas Steels Ltd., Garretts Lane, Birmingham, 33, a new firm specializing in Special Alloy Steels and associated with Monks & Crane Ltd. **Mr. P. W. Gudgeon** has succeeded Mr. W. Duckett as the Northern Area Manager of Monks & Crane Ltd., at their Manchester Office.

Black & Decker Ltd., announce the appointments of **Mr. F. W. McCartney** as Assistant General Manager and **Mr. W. O. Bell, A.M.I.P.E.,** as Acting Production Director.

The Sheffield Laboratories of The British Iron & Steel Research Association are now under the charge of **Dr. J. Pearson, Ph.D., M.Sc., F.R.I.C.** As Assistant Director he retains the Headship of the Steelmaking Division, while **Mr. E. W. Voice** is now responsible for both the Ironmaking Division and the Chemistry Department. **Mr. R. Mayorcas** will be appointed Head Deputy of the Steelmaking Division. **Mr. W. C. F. Hessenberg,** Deputy Director, has relinquished control of the Mechanical Working Division to devote his time to his other activities and **Mr. J. G. Wistreich** now becomes head of this Division, with **Mr. S. S. Carlisle** as Deputy Head.

Mr. C. J. V. Lawson, M.I.E.E., M.I.R.E., is now Deputy Engineer-in-Chief of Cable and Wireless Ltd., and, from 1st April, 1957, will become Engineer-in-Chief following the retirement of **Mr. J. A. Smale, C.B.E., A.F.C., B.Sc., M.I.E.E. Mr. W. J. Knight, M.B.E.,** Deputy Engineer-in-Chief since 1955 is retiring on 31st December this year.

Sir Archibald Gill, B.Sc.(Eng.)., M.I.E.E., F.I.R.E., has joined British Telecommunication Research Ltd. as Director and General Manager. **Mr. F. O. Morrell, B.Sc., M.I.E.E.,** has been appointed Engineering Director of The Automatic Telephone & Electric Co. Ltd., and his Technical Assistants, **Mr. J. Lawton, M.Sc., M.I.E.E.** and **Mr. G. T. Baker, M.Sc.,** have been appointed to the Board of British Telecommunications Research Ltd., responsible for research work on transmission and switching respectively.

Mr. Donald A. Bennett has been appointed General Manager of International Synthetic Rubber Company.

Peregrine & Partners announce that **Mr. C. J. Mole, A.M.I.E.E.** has joined them as a consultant.

Mr. C. N. Kington, M.B.E., B.Sc., M.I.Mech.E., M.I.E.E., has joined Husband & Co. as Chief Mechanical and Electrical Engineer.

The Caterpillar Tractor Co. Ltd., announce that Mr. Dennis **H. Gilliver** has been appointed as Secretary, Mr. Graham **W. Almrott** becomes Manager of the Company's operations at Desford, Leicester, **Mr. Thomas V. J. Armstrong** is the new Merchandise Manager and that **Mr. B. W. Warren** is now the Parts Office Manager.

Mr. G. Ensor, B.Sc., A.M.I.E.E., a Director of Fielden Electronics Ltd., Manchester, has been appointed as General Manager and **Mr. V. Thomas** is the General Sales Manager covering all home and export sales.

At the recent Annual General Meeting of the Norton Grinding Wheel Co. Ltd., **Mr. A. E. West,** Chief Accountant, and **Mr. John B. Morrison,** General Works Manager, were both appointed directors of the Company.

Keith Blackman Ltd., announce that from 1st August three new appointments were made to their Board. **Mr. C. J. Atkins** is now Sales Director, **Mr. F. W. Goodge** is Contracts Director while **Mr. S. Hudson** is a director and London Works Manager. **Mr. A. H. Woodley** was also made Sales Manager.

Mr. E. H. L. Cooper, M.I.Mech.E., M.I.E.E., leaves his position as Works Director and General Manager of Henry Meadows Ltd., upon his appointment as Managing Director of A. C. Morrison (Engineers) Ltd., another company in The Associated British Engineering Group.

Metropolitan-Vickers Electrical Co. Ltd., have announced that **Mr. E. Tankard** has been appointed Comptroller, **Mr. A. Cooper** as Accountant and **Mr. A. G. Evans** as Assistant Accountant. **Mr. E. Salmon** has retired from the Company and is succeeded by Mr. E. Tankard.

Colonel Sir Harold Smith has been reappointed Chairman of the Gas Council when his present term expires on 31st December. **Sir Henry Jones** has been reappointed as Deputy Chairman from 1st February.

In recognition of his services to the British Electrical Development Association and the Industry, **Mr. H. Franklin Carpenter** has been made Vice-President of the Association. Mr. Carpenter is Chairman of the Electricity Authority of Cyprus and a member of the South Eastern Electricity Board.

Richard Thomas and Baldwins have appointed **Sir Hugh Beaver** and **Sir John Green** as Directors. Sir Hugh Beaver is Managing Director of Arthur Guinness Son & Co. Ltd., and a Director of The Colonial Development Corporation. Sir John Green is Chairman of Thos. Firth and John Brown Ltd.

Following the recent retirement of **Mr. H. V. Harris** as Chairman and Managing Director of Bennis Combustion Ltd., Little Hulton, Walkden, Manchester, the Board of Directors announce the election of **Mr. George Moreton Mellor** as Chairman of the Company, and the appointment of Mr. Mellor and **Mr. Fred Howarth** as Joint Managing Directors.

Mr. David H. G. Ince, D.F.C., B.Sc., has joined British Oxygen Aro Equipment Ltd. as Sales Manager.

International Synthetic Rubber announce the appointments of **Mr. Kenneth G. Burridge** as Works Manager of the new plant now being erected at Fawley. **Mr. Alastair F. Crawford** has been appointed Secretary and Accountant.

Wolverhampton Metal Co. Ltd announce that **Mr. A. Gillott** has been made Secretary in succession to **Mr. R. M. Parker** who is going to Australia. Mr. R. J. Hughes is now the Deputy Secretary.

Mr. D. F. Mann has been appointed by the Ministry of Works to succeed **Mr. W. T. Lewis** as the North West Regional Director.

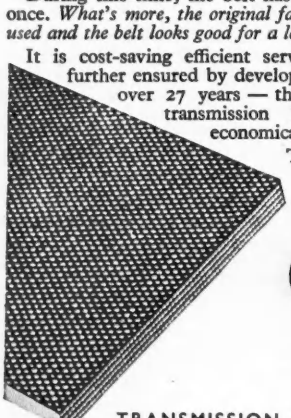
Factory's main drive has used the same Goodyear belt for 27 years

The twenty-seven-year-old Goodyear Thor belt in service at the Wishaw factory. It has been taken up only once.

Continuous and trouble-free service for 27 years. That's the record of the Goodyear belt on the main drive at the Wishaw factory of Messrs. J. Shortland & Co. Ltd.—manufacturers of all types of nails. It's a 7 ply Thor belt, 10 ins. wide by 46 ft. long, and is on a 60 h.p. oil engine drive, which has been running since January, 1929.

During this time, the belt has been taken up only once. *What's more, the original fasteners are still being used and the belt looks good for a lot more service yet.*

It is cost-saving efficient service like this—now further ensured by development in belt design over 27 years — that makes Goodyear transmission belting the most economical for every drive. To minimise *your* transmission costs, fit Goodyear Amber Thor Square Edge. Its plies of silver duck are securely bonded together by skim coatings of strong, resilient rubber. This ensures the greatest possible fastener security, flexibility, and freedom from ply separation.



Amber Thor has accurately cut edges for true running and a rubberised gripping surface to safeguard against slippage and power wastage. Like all other Goodyear transmission belts, Endless Cord, Klingtite and Pathfinder, it is rendered immune to the deteriorating effects of mildew.

QUICK DELIVERY

Always specify Goodyear belting. Sizes in regular demand are always in stock. Contact your nearest Goodyear distributor — or The Goodyear Tyre and Rubber Co. (G.B.) Ltd., Industrial Rubber Products Department, Wolverhampton.

GOODYEAR

INDUSTRIAL RUBBER PRODUCTS

TRANSMISSION BELTS · V-BELTS · CONVEYOR BELTS · HOSE · FENDERS

The Cementation Co. Ltd. have promoted **Mr. F. G. Atherton** and **Mr. C. F. Grundy** as Directors following their many years as Executives of the Company.

Mr. R. P. Richardson has joined the Board of Metachemical Processes Ltd., of Acton and Crawley. Mr. Richardson was formerly Managing Director of Burndept Ltd.

Mr. S. E. Gillies has joined the Railway and General Engineering Co. Ltd., as the Director of Sales.

The appointment of **Mr. W. B. Fenwick, M.I.E.E.**, as Deputy Works Manager has been announced by A. Reyrolle and Co. Ltd.

Babcox and Wilcox, Ltd., announce that their Atomic Energy Department will operate from 2nd October under the direction of **Mr. W. F. C. Schaap**, the Company's Chief Engineer. **Mr. T. B. Webb** has been made Chief Engineer and Manager of the Department with **Mr. W. R. Wootton** as Assistant Manager. **Dr. W. B. Carlson** is to succeed Mr. Webb as Chief Research Engineer to the Company.

New appointments in the Instrument and Meter Department of Metropolitan Vickers Ltd. are **Mr. R. M. A. Smith, M.I.E.E.**, as Sales Manager and **Mr. A. H. Gray, M.I.E.E.**, as Assistant Chief Engineer. Mr. Smith has succeeded **Mr. R. H. Knott** who will continue to act as an adviser to the Department.

Powers-Samas Accounting Machines Ltd. announce that **Mr. F. W. Hutchins** and **Colonel F. T. Davies** have been appointed to the Board. Mr. Hutchins becomes Director of Production succeeding **Mr. T. R. Swift**, who is retiring from the Board at his own request.

Mr. Geoffrey W. Hall has been appointed as Managing Director of Fairey Aviation Co. Ltd., in succession to **Sir Richard Fairey** who continues as Executive Chairman. **Mr. L. Massey Hilton** has relinquished the duties of Assistant Managing Director on medical advice, but will continue to serve on the Board.

Mr. T. J. H. Griffiths has been co-opted a director of the Tor Investment Trust and American Canadian and General Investment Trust.

Brigadier A. L. W. Newth has been appointed chairman of the South-Western Regional Board for Industry from 1st October, in succession to **Colonel Mark Whitwill**, who has resigned to lighten his responsibilities.

Brigadier Newth is a former chairman of the Bristol and Bath District Advisory Committee of the South-Western Regional Board for Industry. He is chairman and managing director of Charles Newth and Sons.

Mr. W. Morgan Thompson, sales director of Monsanto Chemicals Ltd., has been appointed a director of Monsanto Plastics Ltd., a wholly owned subsidiary of Monsanto Chemicals Ltd.

Dr. G. B. B. M. Sutherland will take up his appointment as director of the National Physical Laboratory on 14th September.

Dr. H. W. Melville, F.R.S., has taken up his appointment as secretary of the Department of Scientific and Industrial Research.

Aveling-Barford Ltd., Grantham, announce the appointment of **Mr. G. M. Warren** as local director and member of the board of management.

Mr. H. Livingstone has resigned from the Board of Skil Engineers Ltd., Chell Street, Manchester 12, and **Mr. Edward C. Stevens, M.A., B.Sc.Tech., A.T.I., M.I.Plant.E.**, is now Managing Director. Mr. Stevens was previously Engineering Manager of Sunnyside Weaving Ltd., Bolton, a subsidiary of Tootal Ltd.

Mr. W. R. L. Hosier has resigned as a director of Vaughan Bros. (Drop Forgings) Ltd.

Renold Chains Ltd. announce that **Mr. John Philip Halpin** has been appointed general administration manager.

The Directors of the British Oxygen Company Limited announce that at a Board Meeting held on 5th September, **Lord Reith** was appointed a director of the Company.

Mr. L. Drucquer, M.I.E.E., was appointed a director of The British Thomson-Houston Company Ltd. on the 29th August, 1956, with special responsibility for Home Sales.

Venner Limited has appointed three new directors. **Lt. Col. Laurence Bingham** the General Sales Manager is now Sales Director ; **Mr. Edward Tauchert, M.I.Mech.E., C.M.B.H.I.**, the General Works Manager is now Works Director ; **Mr. W. H. Marsden, A.C.A.**, Secretary of the Company, is now also a director.

British Insulated Callender's Construction Company Ltd. announce that **Mr. C. O. Boyse, B.Sc., M.I.C.E., M.I.E.E., Fel.A.I.E.E.**, has resigned from the Board and General Managership of the Company on his appointment to the Management of the Automatic Telephone and Electric Company Ltd., and that **Mr. O. J. Crompton, M.Eng., M.I.E.E.**, and **Mr. G. H. Walton** have been appointed Joint General Managers as from 1st September, 1956.

Sheepbridge Engineering Limited announce that **Mr. J. H. Lomas** has been appointed Managing Director of their Subsidiary Company, Harold Andrews Sheepbridge Limited, of Halesowen, Birmingham. Mr. Lomas is also Managing Director of Sheepbridge Equipment Limited, Sheepbridge Stokes Limited and British Van der Horst Limited. **Mr. W. J. Collard** has been appointed Director and General Manager of Harold Andrews Sheepbridge Limited. Mr. Collard was previously the Secretary of W. E. Bray & Company Ltd., of Feltham, another member of the Sheepbridge Engineering Group. W. E. Bray & Company Limited, a subsidiary of Sheepbridge Engineering Limited, makers of the well-known range of Brayloaders, announce that **Mr. E. J. Woolf** has resigned his position as Joint Managing Director. **Mr. R. W. T. Bray** has been appointed Managing Director. **Mr. H. Gunner**, who is Managing Director of the Southern group of companies of the Sheepbridge Engineering Group, has joined the board of W. E. Bray & Company Ltd. **Mr. D. J. Harrowell** has been appointed Technical Director. Mr. Harrowell, who has been with the firm for over nine years, was previously Chief Engineer of the Company and was responsible for the design of the first Brayloader. **Mr. C. Edwards** has been appointed Works Manager of the Company.

Mr. Handel Davies has been appointed Deputy Director-General of Aircraft Research and Development (Future Systems), in the Ministry of Supply.

Mr. Ray Wilson has been appointed divisional managing director of the British Electro Metallurgical Company Ltd., a division of Union Carbide.

Mr. D. R. Love, B.Sc., A.M.I.E.E., has been appointed Manager, Dominions division, of Metropolitan-Vickers Electrical Export Company, Ltd.

Mr. C. Sidney Bache

We regret to announce that Mr. C. Sidney Bache, J.P., chairman of Geo. Salter & Co. Ltd., died on 21st August. Mr. Bache, who was 76, had been a Director of the Company since 1917 and was a Vice-President of the National Union of Manufacturers.

FOR CONSTANT TROUBLE-FREE DUTY USE

Hicycle ... that's the drill!

Hicycle drills thrive on hard work, the harder the better. They have no armature windings to burn out and stay on the job costing practically nothing in upkeep. Their high-power, light weight, constant speed and low running costs give maximum output in the shortest possible time, and great safety—only 72v. to earth. Write for descriptive brochure.

TYPICAL EXAMPLES FROM THE RANGE

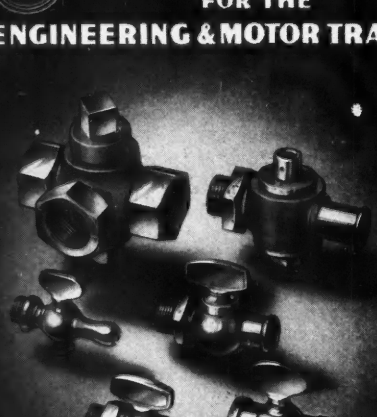
Model No. 256 — Ideal for heavy ⅜" and ½" drilling.

The No. 157 drill combines power with lightness for ⅜" and ½" drilling.

Hicycle PRODUCTION TOOLS

MANUFACTURED BY CONSOLIDATED PNEUMATIC TOOL CO. LIMITED 232 DAWES ROAD LONDON SW

SPECIAL COCKS
FOR THE
ENGINEERING & MOTOR TRADES



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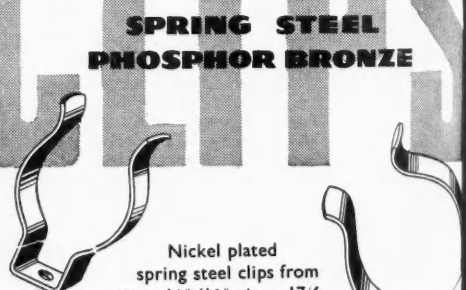

Nickel plated spring steel clips from ¼" to 1½" (1½" size—17/6 gross net), tool clips in the same material and sizes, phosphor bronze clips from 9 mm to 22 mm —say when ! There are lots of variations on the same theme a if it isn't in stock we can soon make it. Better get in to with Lewis of Redditch today.

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BUSINESS NOTES

The Silver Jubilee of the **Dowty Group of Companies** is commemorated by the issue of a most interesting and detailed brochure describing the 25 years' progress of the Group.

A new 16 mm. film is available from **Wickman Ltd.**, with the title, " Designing and Applying Carbide Tools ". This film, which runs for 35 minutes, has a spoken commentary and covers the subject under four broad headings, 1. The functional relationship between single point tools, and milling cutters, drills and reamers, 2. Tool design and terminology, 3. Factors affecting tool design, and 4. Factors affecting tool application.

A continuous trichloroethylene degreasing plant of particular interest has just been delivered by **Imperial Chemical Industries Ltd.** to the Dunlop Rim and Wheel Company Ltd.

A specially designed laboratory, the first in the British rubber industry, for the irradiation of rubber and plastics, has been completed at **Dunlop Research Centre, Birmingham.** Close co-operation has been maintained with the Atomic Energy Research Establishment at Harwell on all the constructional details and technical points involved.

" National scale developments of atomic energy have so enormously increased the availability of sources of radiation," says Mr. E. A. Murphy, director of research, " that it is now possible to envisage their application on an industrial scale. For a considerable time now, irradiation of rubber and plastics has featured in our research programme and we shall now be able to carry out a planned scheme of research."

A three-day Convention on Materials Handling is being organized by the Materials Handling Sub-Committee of the **Institution of Production Engineers,** and will take place at Leamington Spa, Warwickshire, from Thursday, 27th September, to Saturday, 29th September. The Convention theme—" Better Handling—Do It *Now* ! "—is intended to underline the fact that improved materials handling lies within the immediate reach of the production engineer, and does not necessarily involve vast reorganization or the purchase of expensive equipment.

We are advised by **British Paints Limited** that their well-known "Superlative " Gloss Paint is now being made to an entirely new formulation resulting in a finish which will be even more acceptable to the Trade. This has been done by combining the best qualities of " Luxol 1 " and " Superlative " Gloss Paint.

Under a recently-announced agreement with **Giannini Ltd.**, of 45 Gresham Street, London, E.C.2 (the British affiliate of the American company G. M. Giannini and Co. Inc. of Pasadena, California), **Elliott Brothers (London) Limited** are to manufacture and market Giannini shaft-rotation digitizers.

Plans to open a new **Hyster Company** tractor equipment assembly plant near Glasgow, Scotland, on the Clyde river have been announced by Ernest G. Swigert, president of Hyster Company, U.S.A. The new plant will meet overseas demands for certain lines of Hyster construction and logging equipment and will supplement Hyster's manufacturing plant established in Nijmegen, The Netherlands, in 1952. Operations at the Scottish plant will commence later this year. Also announced were plans to open a new manufacturing plant at Sao Paulo, Brazil.

The Annual Report of the **British Standards Institution** for the year ending 31st March, 1956, has just been published.

The Canadian Trade Index containing a wealth of information about Canadian manufacturers and their products in a single hard-covered volume, has just been published by the Canadian Manufacturers' Association.

Enfield Cables Ltd. announce that their London Branch has moved from 1 The Colonnade, Victoria House, Southampton Row, London, W.C.1, to larger premises at 19/21 Store Street, London, W.C.1 (opposite The Building Centre). The greatly improved facilities of these new premises will make daily deliveries to industry possible from an ample stock of Enfield cables and cable accessories.

Five new service and spare parts centres have been established in Germany by **F. Perkins Ltd.**, the Peterborough diesel engine company, to augment its present service arrangements. The centres will cater for both agricultural and industrial engines. In addition to facilities provided by Perkins distributor Sepp Mitteregger at Starnberg (Bayern), service and spare parts centres will be at Stuttgart, Frankfurt-am-Main, Munster, Hildesheim and Bad Oldesloe. German firms offering Perkins diesel engines as standard power units include Claas, B.T.G., Dechentreiter, Famo, Kemna, Lanz and Nordtrak.

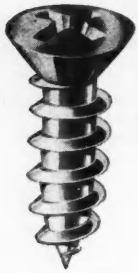
Plans have now been approved and contracts placed for **Brook Motors** new factory at Honley, near Huddersfield. Work is to start immediately on the building which is scheduled for completion in twelve months' time.

Metropolitan-Vickers Electrical Co. Ltd., whose main works are in Trafford Park, Manchester, is to build an extension to its works at Attercliffe Common, Sheffield. The Company has leased from the Sheffield Corporation a site of 21 acres for this extension, and construction of the first section will begin at once. When completed the new extension will double the existing capacity for the manufacture of railway traction motors and generators.

To consolidate associations and agreements made with a number of United States companies in recent years, **The Plessey Company Limited** has just formed an American corporation for the representation and control of its interest in that country. The new corporation, to be known as Plessey Incorporated, has been constituted under the laws of the State of Delaware. Offices are at 41 East 42nd Street, New York City. The Plessey offices in Chicago are being closed immediately and, in future, all the company's American affairs will be handled centrally through the New York headquarters. President of Plessey Incorporated is Mr. W. J. Sinsheimer.

Located at Leigh Park Estate, Havant, near Portsmouth, a new plant now forms a section of the Components Group of **The Plessey Company Limited** of Ilford, Essex, and it is being progressively expanded for the production of switches, coil winding products, variable capacitors and a number of new components which are under development. It is anticipated that, in about a year's time, the total floor space will be 276,000 square feet.

Honeywell-Brown Ltd. announce that a new Branch Office has been opened at 123 Cumberland Road, Dundonald, Belfast, under the supervision of Mr. W. J. Edwards, and offers expert assistance with the choice, installation, and maintenance of the Company's industrial instrumentation, precision snap action switches, and automatic controls for heating and air conditioning systems.



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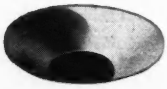

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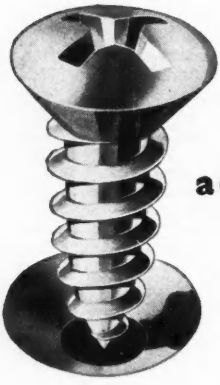

advantage

With steadily-rising labour costs, every non-essential operation along the production line assumes increasing significance. One of these recurring operations has been the precision thread-cutting of screw holes, which, in assembly, have (equally precisely) to be registered together.

But the tapping, self-locating screw eliminates all this, and permits assembly by less-skilled labour. And the cross-recessed head version is designed for use with power-drivers — without a scratch of damage to worker or job.

The tapping screw is demonstrably quicker — cheaper — stronger — safer than the conventional machine screw.

Such plain advantages pay such handsome dividends!

in self-tapping screws

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SLOTTED AND PHILLIPS RECESSED HEAD MACHINE SCREWS AND TAPPING SCREWS • HIGH TENSILE HEXAGON HEAD BOLTS AND SETSCREWS • AIRCRAFT BOLTS, SCREWS AND RIVETS • SEMS • RIVNUTS • CUSTOMS DESIGNED COLD FORGED FASTENERS ALEX SCREWPLUGS.

Associated British Engineering Limited announces that as from 1st September, 1956, their London address, to which all communications should be sent is : 37/41 Bedford Row, London, W.C.1. Telephone No. HOLborn 6881/5.

Associated British Engineering Limited announces the formation of a new wholly-owned subsidiary company, **Associated British Engineering (Canada) Limited,** with head office in Montreal, P.Q. This Canadian subsidiary has in turn acquired The Hepworth Lachine Engineering Company, also of Montreal. Mr. Lawrence Robson, Chairman of Associated British Engineering Limited, the parent company in U.K. becomes Chairman of the two Canadian subsidiaries. Mr. R. G. Fuller, resident in Montreal, has been appointed Managing Director of Associated British Engineering (Canada) Limited, and a Director of Hepworth Lachine Engineering Company.

The Hoffmann Manufacturing Co. Ltd., Chelmsford, Essex, announce that they have changed their Stockroom address from 19 Bury Place to 19 Store Street, London, W.C.1. A comprehensive range of well-known Hoffmann Ball and Roller Bearings will be carried whilst an engineering service is available as previously from their London Office nearby at 8 Bedford Square, W.C.1.

The purchase of the factory, plant and stock-in-trade of The Birtley Company Ltd., at Birtley, County Durham, by **Caterpillar Tractor Co. Ltd.,** has been announced by W. J. Bornholdt, Managing Director. The Birtley Company has, for the past nine years, been manufacturing earthmoving equipment under licence from the American parent of British Caterpillar and this manufacture will be continued and expanded. Col. R. T. Edwards, Managing Director of the Birtley Company, will continue in charge as Manager of the Caterpillar operations at Birtley and becomes a member of the Board of Directors of Caterpillar Tractor Co. Ltd.

At the Witton Engineering Works of **The General Electric Co. Ltd.** the already extensive training facilities have recently been augmented by the establishment of a new machine shop devoted exclusively to the instruction of apprentices.

Elliott Brothers (London) Limited announce that they have concluded a Licence and Technical Agreement with the Swartwout Company of Cleveland, Ohio, by which they become the Manufacturing Licensee and Sole Agents in the British Commonwealth (except Canada) and Europe for the complete Swartwout range of "Autronic" Control and Transmission Equipment.

Two new plants, each of 10,000 tons capacity, have been planned for north and south India to make the country self-supporting in aluminium. The plants are on the sites of two hydro-electric plants at Rihand and Pyar. A 10,000 ton plant has also been sanctioned for the Hirakund area of Orissa while the Assensol plant capacity is being doubled to 5,000 tons.

Dominion Magnesium has announced the production of lithium at the company's Haley, Ontario, Canada, plant, so adding another metal to the range of Canadian mining. This marks the first occasion on which lithium in its metallic form has been produced in Canada on any regular basis.

Parmiter Hope and Sugden Ltd., electrical engineers of Manchester, who manufacture switch and fuse-gear under the trade names of Aeroflex and Fluvent, has arranged to acquire the share capital of J. F. Collier and Co., of Macclesfield, engineers and brass and iron founders.

Gloster Aircraft Co. Ltd., a member of the Hawker Siddeley Group, has established a new Technical Developments Division aimed at making the company's experience of jet aircraft technology available to industry generally. The Division will occupy a new 35,000 square feet engineering research establishment now under construction.

The South African Cabinet has decided to investigate the possibility of using nuclear power in the Union. Dr. Van Rhyn, the Minister of Mines, will announce the appointment of a commission to investigate the question of establishing an atomic power station in Western Cape Province, the part of the Union farthest from sources of coal.

The first large germanium power rectifier equipment to be installed on the Continent was put into service at Pechiney's St. Jean-de-Maurienne Factory, Paris, a few days ago. Made by **British Thomson-Houston Co. Ltd.,** the equipment consists of two 1000-kW, 250-volt, 4000-amp fan-cooled germanium power rectifiers.

An agreement to exchange all patents and technical information relating to petrol injection systems has been reached between **Joseph Lucas (Industries) Ltd.** and the Holley Carburetor Company of Detroit, U.S.

Further developments in the manufacture of new industrial chemicals from petroleum were announced by **Monsanto Chemicals Ltd.** The company propose to spend some £8,500,000 on the first stage of a long-term expansion programme. The first plant to be erected will be for the manufacture of 10,000 tons of polyethylene a year. The next products in the company's programme will be copolymers of acrylonitrile, butadiene, and other monomers. After this a major plant would be constructed for the manufacture of acrylonitrile, a chemical not yet made in Britain.

The Northern Ireland Minister of Commerce announces that the Advance factory now nearing completion at Ballymena, Co. Antrim, is to be occupied by Flexibox Ltd., a member of the Manchester Oil Refinery (Holdings) group.

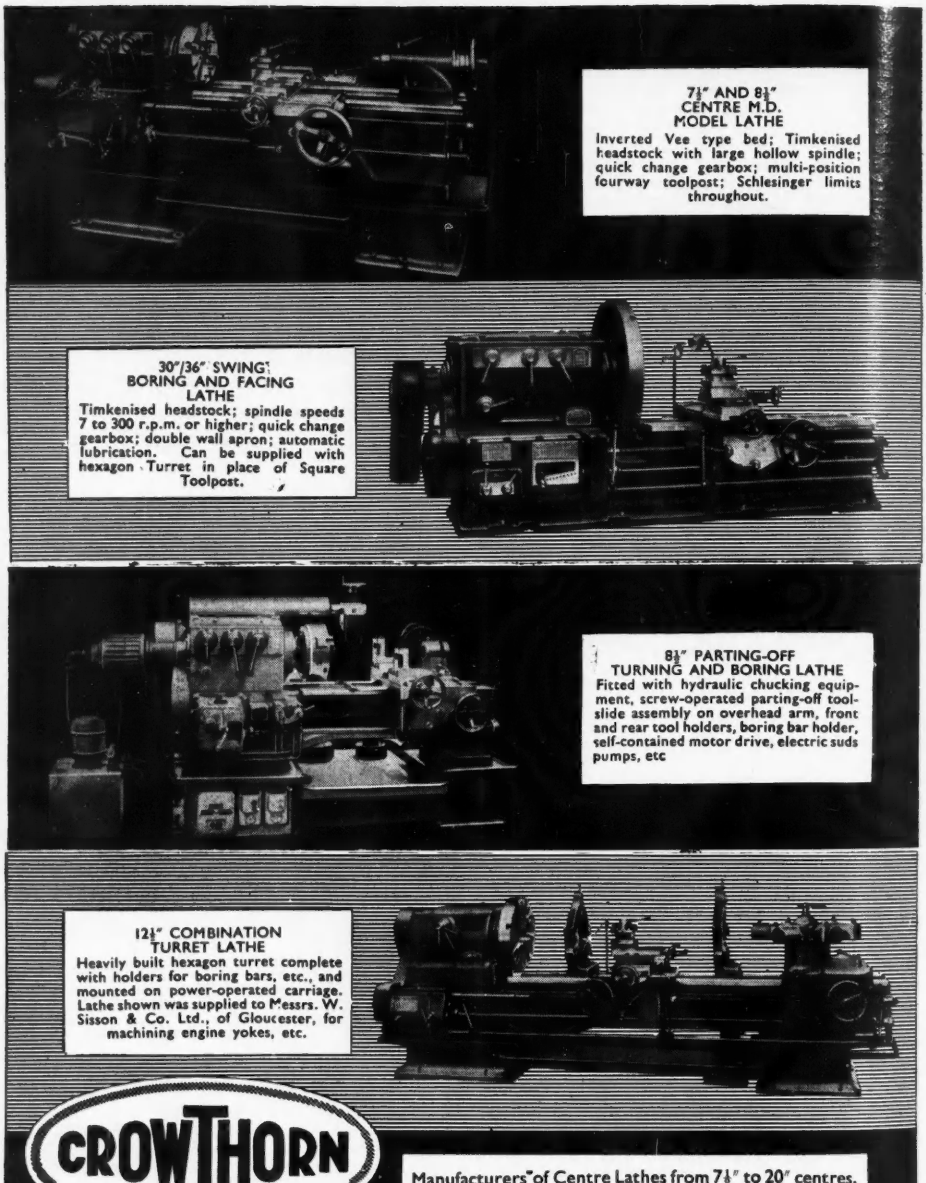
Another stage in the expansion of production resources at the **Wickman Ltd.** Banner Lane factory has reached fruition with the completion of this new extension providing an additional 24,000 square feet, which together with double-shift working will substantially expand production of multi-spindle Automatics.

Midland Silicones Ltd. announces that arrangements ments have been made for the additional distribution of silicone electrical insulating compound "MS4" by the British Central Electrical Company Ltd., 6 and 8 Rosebery Avenue, London, E.C.1.

The Crittall Manufacturing Company Ltd. announces that it has joined the Arcon Group. Existing members of the group are I.C.I. Ltd., Stewarts and Lloyds Ltd., United Steel Companies Ltd., and Taylor Woodrow (Building Exports) Ltd.

Preliminary work has started on the site for the erection of the new **Pilkington-Chance** optical factory at St. Asaph, Flintshire.

The contractors, Holland & Hannen Cubitts, of London, are expected on the site by 10th September and it is hoped that steel work will be completed by the end of September. The roof is expected to be completed by the end of January next year and in March the installation of the major plant should start.



7¼" AND 8¼"
CENTRE M.D.
MODEL LATHE
Inverted Vee type bed; Timkenised headstock with large hollow spindle; quick change gearbox; multi-position fourway toolpost; Schlesinger limits throughout.

30"/36" SWING
BORING AND FACING
LATHE
Timkenised headstock; spindle speeds 7 to 300 r.p.m. or higher; quick change gearbox; double wall apron; automatic lubrication. Can be supplied with hexagon Turret in place of Square Toolpost.

8½" PARTING-OFF
TURNING AND BORING LATHE
Fitted with hydraulic chucking equipment, screw-operated parting-off toolslide assembly on overhead arm, front and rear tool holders, boring bar holder, self-contained motor drive, electric suds pumps, etc

12½" COMBINATION
TURRET LATHE
Heavily built hexagon turret complete with holders for boring bars, etc., and mounted on power-operated carriage. Lathe shown was supplied to Messrs. W. Sisson & Co. Ltd., of Gloucester, for machining engine yokes, etc.

CROWTHORN
HIGH CLASS MACHINE TOOL MAKERS

Manufacturers of Centre Lathes from 7¼" to 20" centres, 30" and 36" swing Boring and Facing Lathes with square or hexagon turret. Combination Turret Lathes; 19" stroke shaping machines.

CROWTHORN ENGINEERING COMPANY LIMITED
REDDISH · STOCKPORT · ENGLAND
Phone: STOCKPORT 2067-8 *Grams: CROWTOOL, REDDISH*

Compoflex Co. Ltd., 23–25 Northumberland Avenue, London, W.C.2, have just appointed Armstrong Elliot (Engineers) Ltd., 39 Side, Newcastle upon Tyne, as regional stockists and agents for Wyrem dust extraction and ventilation hose covering Tyneside and the Northern counties generally. They also have a Branch Stores at 62 Church Road, Stockton-on-Tees.

Since the announcement that the next **British Plastics Exhibition**—being held from 10th–20th July, 1957—is to become an *international* event, and will therefore include exhibits from other countries, so many requests for stand space have been received that the National Hall has been booked in addition to the Grand Hall at Olympia. This now gives a total floor area of 250,000 sq ft, compared with 90,000 sq ft in 1955—the Exhibition is held every other year.

The Fuel Efficiency Exhibition at Olympia, from 2nd–10th October, is to be opened by the Minister of Fuel and Power, Mr. Aubrey Jones, M.P. Important statements about the efficient use of fuel in industry will be made at a Conference that will take place in conjunction with the Exhibition.

Sheepbridge Engineering Limited announce that agreement has been entered into with Gebr. Eickhoff Maschinenfabrik u. Eisengiesserei, m.b.H., Bochum, Germany, for the manufacture at the Chesterfield Works of Sheepbridge Equipment Limited of components for the well-known Eickhoff Steel Plate Mining Conveyors. Sales of Eickhoff Conveyors will be handled by W. Stanley Jones (Engineers) Limited of Altrincham, Cheshire, and E. Wheatley, Limited, of Sheffield, as at present.

Mr. N. McKinnon Wood, Chairman of the **British Laboratory Ware Association,** has announced that the Laboratory Furnishers who are members of the Association have decided to stabilize the Home and Export prices of the laboratory equipment and apparatus, other than chemicals, they manufacture and distribute, for a period of 6 months from the 1st September, 1956.

It is announced that Simms Motor Units Ltd. have acquired the design and manufacturing organization of R. F. Landon & Partners, Craven House, Kingsway, W.C.2. A limited company has been formed, and the Directors of the new **R. F. Landon & Partners Ltd.** are Mr. G. E. Liardet (chairman), Mr. R. F. Landon (managing director) and Messrs. J. Ayres and R. G. Sutton. Production of fully-automatic oil burners under the trade name of " Kingsway ", will now take place at a modern factory at Colnbrook (Bucks.).

Newport Instruments (Scientific & Mobile) Ltd., Newport Pagnell, Bucks., announce the availability of a new service to industry. Based on their experience of installing mobile equipment units for Government Departments, they now have a section specializing in the design and construction of special caravans which are fitted out with the customers' own equipment. Where a company already have a mobile unit available Newport Instruments will carry out the installation or redesign work necessary.

The most modern grease unit in Europe forms part of a new lubricating oil blending installation which has recently come into service in Austria. Planned by Shell in 1950 these facilities will add materially to the domestic output of high-grade products, which previously had to be imported to meet increasing industrial demand. The combination of the new units and the refinery at Floridsdorf will enable **Shell Austria A.G.** to manufacture 75% of the products it requires for home markets using indigenous raw material almost exclusively.

The sale of a Soviet industrial licence for turbo-oil drilling equipment is reported by the **Handelsblatt Salzgitter Well Drilling Equipment Company.** The Düsseldorf concern, Haniel and Lueg, is to start manufacture of turbo-drilling equipment under the Soviet licence by the end of this year.

The Steel Company of Wales Ltd. announced recently that its Elba Works, which carries out the hot dip tinning operation for its cold reduction mill at Velindre, has produced the first tinplate since its modernization.

Elba Works is being re-equipped with seven Melingriffith tinning machines and of these one has so far been brought into operation.

Alfred Herbert Ltd., Factored Division, Red Lane Works, Coventry, announces that it has been appointed sole selling agent in the United Kingdom for Gildemeister automatics.

Ferodo Limited has received a contract worth more than a quarter of a million pounds (Australian) for the supply of non-metallic brake blocks from the New South Wales Government Railways in Australia for their electrified suburban lines.

Teddington Aircraft Controls' recently formed Industrial Bellows section will now be based at Ammanford, where their factory is in full production. Teddington industrial bellows are being made in collaboration with the Solar Aircraft Company of San Diego, U.S.A.

Rapid Magnetic Machines Limited, Lombard Street, Birmingham, announce the establishment of a department specializing in Automation and Magnetic Power.

CENTENARY OF E. G. ACHESON

The year 1956 sees the centenary of the birth of Edward Goodrich Acheson. His best known contributions to industry are, perhaps, carborundum and the electric-furnace graphite. E. G. Acheson was also successful in the colloidalizing of graphite.

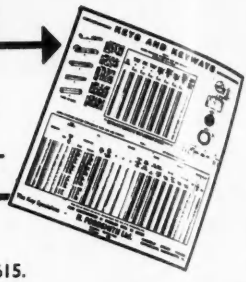
The fifty or so dispersions of colloidal graphite now marketed under the trade mark " dag " have virtually unlimited applications in all branches of industry. Apart from the lubrication of all manner of mechanical equipment, " dag ", colloidal graphite is extensively used as a high-temperature and anti-seize lubricant, for the lubrication of dies in hot-metalworking operations, as conducting coatings in the electrical and electronic industries, as opaques in photolithography, for boiler scale prevention, to mention only a few of the numerous applications for this versatile product. Leading engine and car manufacturers find it invaluable as an assembly and running-in lubricant. Most of the cathode-ray tubes produced in Great Britain are internally and externally coated with colloidal graphite. Biologists have injected it into the breathing tubes of insects ; printers use it to provide contrast on zincos. Extrusion, forging and wire-drawing dies are extensively lubricated with colloidal graphite. Porous substances, e.g., wood, fabrics, and asbestos impregnated with it acquire electrical and lubricating properties. As a parting agent it can prevent rubber sealing strips from " growing " on metal or glass from sticking to moulds in bottle-making machines. As one of the thinnest opaque films it has a special value in photolithography.

For lubrication at temperatures above the decomposition point of conventional oils and greases colloidal graphite is ideal. It will lubricate satisfactorily at 600°C. Lubrication of bearings, reduction gears, compressors, steam engines, and pumps—there is no end to the list of mechanical equipment on which colloidal graphite is used with great advantage throughout the world.

REPETITION PARTS

Whether standard or special, FORDSMITH repetition parts can be relied upon for quality and service! Wheel keys of all types, taper and cotter pins, collars, studs, bolts and nuts, screws and screwed rod—automatic capstan bar work a speciality!

SEND FOR A **FREE** COPY OF THIS KEY DATA WALL-CHART



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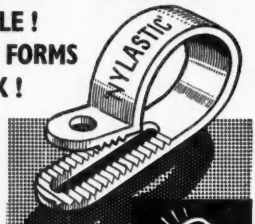

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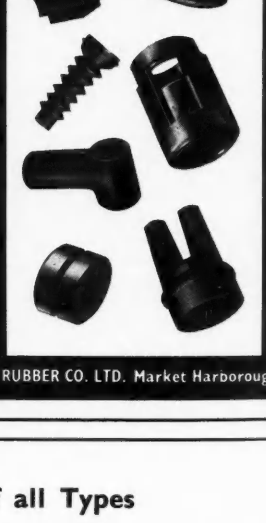

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THYNNE ENGINEERS LTD.

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BOLTON

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CONTRACTS

Standard Telephones and Cables Limited have just been awarded an important contract by the British Post Office to manufacture and install a new Automatic Telephone Exchange at St. Albans, Hertfordshire, for service in 1959.

A power plant which will be operated by remote control through a radio link from a station twelve miles away is to be equipped by **The English Electric Company Limited** for the Electricity Commission of New South Wales. The new station is to be built on the Warragamba River, at a point about twelve miles from Penrith, as part of the Warragamba Dam hydro-electric project.

An order valued at £750,000 covering the electrical equipment for a 4-stand tandem cold strip rolling mill has been placed with the **British Thomson-Houston Company Ltd.** by the Steel Company of Wales Ltd., Port Talbot.

The British Thomson-Houston Export Company Limited have received a contract worth just over £2,100,000 for the supply and installation of switchgear and other equipment for part of the transmission system at the Kariba switching station and at various sub-stations. A. Reyrolle and Company Limited were awarded a contract worth just over £36,000 for the supply and installation of switchgear.

The Shell Petroleum Company has ordered from **Metropolitan-Vickers Electrical Co. Ltd.** a 4500-kW gas turbine-generator set for base load operation on natural gas. It will be installed at Seria, British North Borneo.

Under a contract recently awarded by the Central Electricity Authority of London, **F. W. Brackett & Co. Ltd.** will design, manufacture and install three double-entry Drum type automatic water screens for continuous day and night operation at the Northfleet Power Station under construction on the north bank of the Thames Estuary.

Birwelco Limited have recently received orders for the supply of four Petro-Chem Iso-Flow Furnaces for use in U.O.P. Platforming facilities which are presently being engineered by Procon (Great Britain) Ltd. for The Trinidad Oil Co. Ltd., at their Refinery at Pointe a Pierre in Trinidad, British West Indies. All of these Heaters are of the radiant integral convection type and are used for the heating of hydrocarbon liquids. Their through-put varies from 238,200 lb/hr down to 87,000 lb/hr.

Procon (Great Britain) Ltd. have ordered from **Brown Fintube (G.B.) Ltd.**, a Birwelco associate, a series of heat exchangers on behalf of Lobitos Oilfield Limited, for use on a new Gas Treating Unit at present being contracted by Procon and designed by Universal Oil Products Ltd. of Chicago.

Two 50-MVA 428-rpm vertical waterwheel generators have been ordered from **Metropolitan-Vickers Electrical Co. Ltd.** by Norges Vassdrags Og Elektrisitetsvesen for extensions at Rossaga, a power station on the fringes of the Arctic Circle. These generators will supply power to an iron works and an aluminium works near the power station.

F. E. Weatherill, Ltd., of Tewin Road, Welwyn Garden City, announce that the British Transport Commission have just placed an order with them for thirteen "Epping Auto-Shunters" for British Railways, and that the Port of London Authority have also placed a repeat order for four Shunting Tractors.

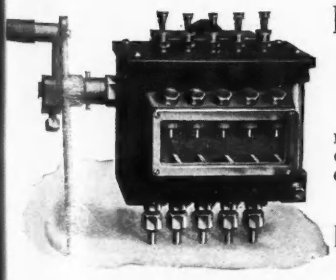
British Insulated Callender's Cables Limited are rebuilding their cable factory at Erith, Kent, as part of a progressive plan for reorganizing their production units. The new factory will be 660 feet long and 580 feet wide and will, it is believed, be the largest in the world concerned solely with the manufacture of power cables.

In the face of world competition, **The National Gas and Oil Engine Co. Ltd.**, Ashton-under-Lyne, has obtained a contract from the Auckland Metropolitan Drainage Board for diesel generating plant for the Manukau sewage purification works, Auckland. The order was placed with National's agents in New Zealand, Turnbull and Jones Ltd., Wellington. Consulting engineers for the scheme are Messrs. Brown and Caldwell, 66 Mint Street, San Francisco 3, California.

A contract for the development of three prototype models of a Rocket Scoring Camera with three dimensional capability has been awarded to the **Reconnaissance Systems Division of Fairchild Camera and Instrument Corporation, U.S.A.**, by the Wright Air Development Center.

The Indian Iron and Steel Company Limited of Burdwan, India, are to install a second 2,000 kVA Birlec Lectromelt Arc Melting Furnace, giving an output of approximately 2 tons per hour. Since 1946 **Birlec Limited** of Birmingham have been commissioned by various Indian companies to build a total of 22 Arc Melting Furnaces.

A new four-high Plate Finishing Mill is now being built for the Appleby-Frodingham Steel Company by **Davy and United Engineering Company Limited** at a cost of over half-a-million pounds, and it will be completed and ready for operation in June 1958.



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Vacancies for the following personnel are available in the various departments of the Organization at Manchester and Woodford, Cheshire and also in the new West London Design Group :—

Aerodynamicists . Structural Draughtsmen . Design Technicians . Mathematicians . Structural Engineers . Control System Engineers . Stressmen . Flight Test Engineers . Flutter Technicians . Mechanical Engineers . Instrument Draughtsmen . Wind Tunnel Technicians . Aircraft Draughtsmen . Trials Engineers . Mechanical Draughtsmen . Electrical Engineers . Electrical Draughtsmen . Internal Flow Engineers . Technical Assistants . Technical Authors . Technical Artists.

In most cases there are junior and senior appointments available, and aircraft experience is not essential.

Successful applicants will find the salaries, opportunities and working conditions are exceptional, and there is an attractive Pension and Assurance Scheme available.

If you think you can fill one of these positions, or if you are interested in entering the AVRO Design, Development or Research groups, please write to :—

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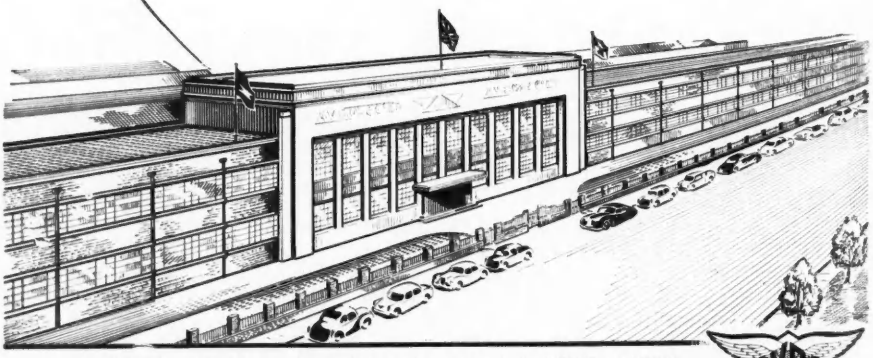
giving particulars of your age, qualifications and experience. All inquiries will be treated in strict confidence.



A. V. ROE & CO., LIMITED.—MANCHESTER

Classified Advertisements

The rate for all classified advertisements is 6d. per word ; in bold print 9d. per word ; minimum order 6s. Box-number advertisements 1s. extra. Instructions, together with remittance, must be received not later than the 3rd of each month for advertisements to appear in the same month's issue.

SITUATION REQUIRED

DUTCH ENGINEER, graduate of Delft Technical University with 3 years' experience in Marine Diesel Engines looks for a suitable job with an Engineering Firm. Ir. I. A. Kreber, Schiedamsweg 137, Vlaardingen, Holland.

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HIGH LEVEL SALESMEN required for new appointments in all areas of Britain by well established specialists in lubrication whose products are internationally known and respected. Our recent advances in lubrication technology necessitate the appointment of executive type men who genuinely have the entrée in the engineering and allied trades. A good salary and a generous commission, together with all necessary expenses and the provision of a new car will be forthcoming to the successful applicants, who should apply with full particulars to Sales Manager, Box No. 21, THE ENGINEERS' DIGEST.

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Armstrong Siddeley Motors Limited offer a good sound job with security of tenure for the right man to experienced Designers and Draughtsmen. The initial salary £700 to £1100. If desired personal and domestic circumstances will be fully considered. Interviews will be conducted by the Chief Designer or Chief Draughtsman. The office has been designed on the most modern lines for excellence of working conditions with an adjacent up-to-date restaurant. Applications in the strictest confidence quoting SE/AN to the Technical Personnel Manager, Armstrong Siddeley Motors Limited, Coventry.

DAVY AND UNITED ENGINEERING COMPANY LTD.

invite applications for the following vacancies:

1. STRUCTURAL DRAUGHTSMAN for Steelworks Engineering Department for work on the Indian Government project at Durgapur, Nr. Calcutta. Duties include layout and design of new factory buildings. Opportunity will arise for transfer of accepted applicant to site at a later date.
2. MECHANICAL DRAUGHTSMAN for Steelworks Plant for the design and detail of steelworks converter plant employing air and oxygen blowing methods. Experience in Drawing Office of open hearth or converter steelworks or plant manufacturer desirable.
3. MECHANICAL DRAUGHTSMEN for the Instruments Division and General Drawing Office for employment on the design of Hot and Cold Strip Mills and Auxiliary Plant. Scope for ingenuity and initiative.

Excellent working conditions. Contributory Superannuation Scheme. Apply : indicating preference with details of age, experience and qualifications to Personnel Officer, Davy and United Engineering Company Limited, Darnall Works, Sheffield 9.

PLANT ENGINEER of administrative status required by Central Scotland Ironfounders and Manufacturers of Cooking and Heating Appliances. Salary offered about £1,400 per annum. Superannuation scheme in operation. Write stating age, experience. Box No. 22 THE ENGINEERS' DIGEST.

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DEVELOPMENT OF USE OF NON-METALLIC MATERIALS IN CHEMICAL PLANT

Graduate Chemical or Mechanical Engineer or Metallurgist required to initiate and carry out plant and laboratory trials on non-metallic materials (plastics, laminates, ceramics, cements, heat-insulation) with a view to their application in existing and projected chemical plant. It is preferred that applicants should have chemical works and plant design experience and some knowledge of non-metallic materials, chemistry and metallurgy. Age 25–35.

The appointment is to the permanent Staff, 5-day week, with good salary, first-class working conditions and recreational facilities. Contributory Pension Fund and Profit-Sharing Schemes. Limited assistance with removal expenses for married men. Apply for official application form to Staff Manager, quoting reference MET/DEV, at I.C.I., P.O. Box No. 7, Winnington, Northwich, Cheshire.

SENIOR DESIGNER/DRAUGHTSMAN required for domestic-appliance development laboratories of Charles Colston Limited, in Kingston Hill area.

Applications invited from fully qualified men with a genuine ability and liking for design work, plus an intimate knowledge of production techniques and conditions. Good salary plus incentive participation. Write fully to :

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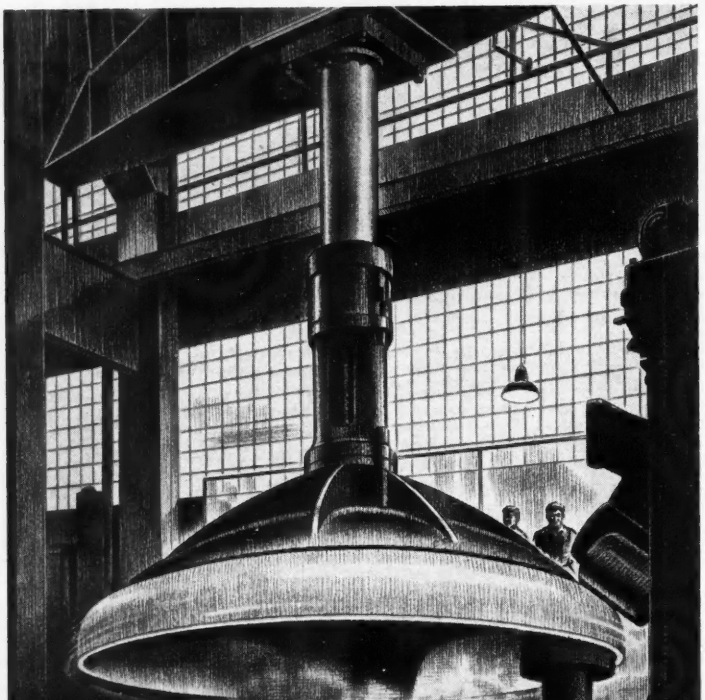

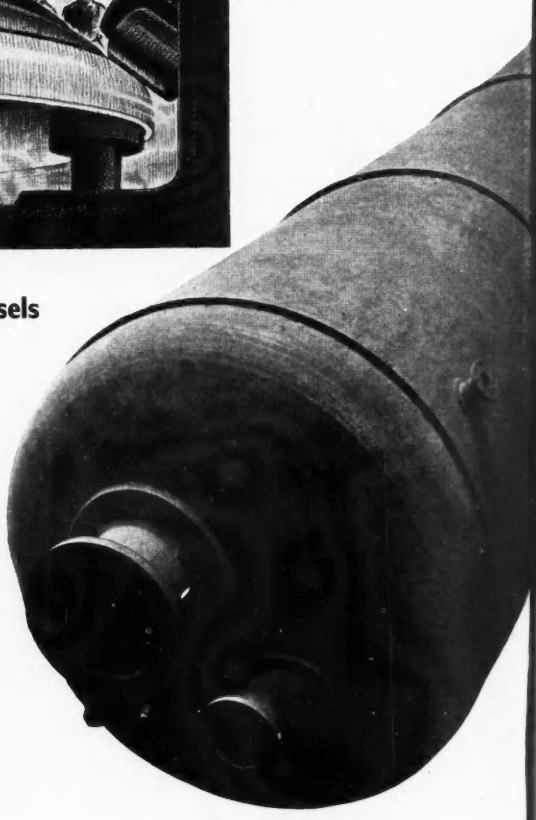

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BOOKS RECEIVED

A Handbook on Belt Conveyor Design. Compiled by the Technical Staff, Materials Handling Department, in association with Hewitt-Robins Inc., New York. 148 pp., 70 illustrations. Publishers : The General Electric Company Limited, Fraser & Chalmers Engineering Works, Erith, Kent. Price : 30/–.

Design problems on belt conveyors require exhaustive study by specialists before suitable installations can be developed. In this volume, the latest of a series of technical handbooks by the General Electric Co. Ltd., Fraser & Chalmers Engineering Works, the experience of many years is collated, including essentials such as belts, troughing and return idlers, head, tail, and bend pulleys, drives, and supporting structures. In addition, full details are given of chutes, take-ups, belt cleaners, and hold-backs, together with variations of straightforward conveyor belts, such as conveyor-type feeders, trippers, etc.

A feature of great value for design offices is a chapter on Fundamental Analyses of Conveyors, while a sample calculation for conveyors, with a description of how the details are worked out, links the various sections of the text. The final section of the book comprises a series of tables and charts, providing ready reference to all data required for conveyor calculations. In short, this interesting and authoritative publication is of undoubted value, not only to those actually engaged in conveyor design but also to students, trainees, and engineers contemplating a conveyor installation.

Abacs or Nomograms. By A. Giet. Translated from the French by J. W. Head, M.A. (Cantab.), and H. D. Phippen, M.A. (Edin.), B.Sc. (London). 235 pp., 152 illustrations. Publishers : Iliffe & Sons Ltd., Dorset House, Stamford Street, London, S.E.1. Price : 35/–.

Most of the comparatively small literature on the subject of nomograms has been written for mathematicians and is usually very difficult for the practical engineer to comprehend. The present work, however, the translation of a book which has enjoyed considerable success in French, does not suffer from this defect. On the contrary, it is essentially practical and not only demonstrates the many and varied applications of the abac or nomogram, but also shows how even those without highly specialized mathematical knowledge may construct their own charts.

The book deals with both Cartesian abacs and alignment charts, and includes a large number of practical examples drawn from the fields of mechanics, physics, and electrical engineering. Specially adapted for English readers and well translated by Mr. Head and Miss Phippen, this edition will undoubtedly prove of great practical interest to engineers and physicists, and, indeed, to many others who require time-saving methods when carrying out repetitive and complicated calculations.

Resistance of Materials. Fourth Edition, 1956. By Fred B. Seely and James O. Smith. 476 pp., 434 illustrations. Publishers : John Wiley & Sons, Inc., New York, and Chapman & Hall, Limited, 37 Essex Street, London, W.C.2. Price : 52/–.

During the thirty years which have elapsed since the first edition of this book appeared, many new engineering problems in the field of resistance or strength of materials have arisen ; similarly, considerable analytical and experimental research and engineering experience have brought out new and valuable information.

This fourth edition by Professors Seely and Smith is, therefore, essentially a new book but, like the previous editions, it is intended for use as a first course for engineering students and for those younger engineers in practice who may desire to give further study to the subject on their own initiative. It successfully achieves its object of making the theory of resistance of metals more self-sufficient and of developing more logical methods of analyses and design. Featured in this revised edition is an early introduction of the inelastic behaviour of materials, especially useful in obtaining the limiting or ultimate loads on certain types of members, such as riveted and welded joints, beams, columns, etc. In addition, a more realistic concept of the safety of a member, together with a more rigorous and flexible treatment of combined stresses, is given, while interaction curves are introduced as a means of solving problems involving combined loads. A more rational treatment of the buckling strength of columns is included, together with a large number of new problems and new figures, many of which emphasize actual physical conditions encountered in engineering practice.

Induction Heating Practice. By D. Warburton-Brown, A.M.I. Mech.E. 192 pp., 166 illustrations. Publishers : Odhams Press Limited, 96 Long Acre, London, W.C.2. Price : 21/–.

Written by a leading British expert in high-frequency induction heating, this interesting and informative book is a detailed and up-to-date study of the process, and deals particularly with its practical application to industrial problems. As such, it is intended for the production engineer or the executive interested in the possibilities of installing or extending induction-heating equipment, for the foreman or operator with the day-to-day job of operating (and sometimes adapting) such equipment, and for all others concerned with heat treatment in engineering production.

With extensive experience to draw upon, the author is able to give invaluable information on the design of work-coils and inductors, on modifying the design of components or assemblies to facilitate use of the process and on jigs or handling mechanisms. The remainder of the book deals with various applications, first giving general notes on each and then going on to specific examples, with full production data. The examples cover a very wide range, from the motor and motor-accessory industries to typewriters, gold-melting, electrical components, and precision instruments, while a complete chapter is devoted to the special problems of gear-hardening.

LATEST INDUSTRIAL LITERATURE

1. Production Guillotine Shearing Machines. In a well-conceived and executed 12-page illustrated brochure, details are given of a series of production guillotine shearing machines, comprising 4, 6, and 8 ft models, capable of handling mild-steel plate up to ½ in. in thickness. These machines incorporate the most modern ideas in shearing, and give more accurate cutting at a high speed and maximum capacity.

Any tendency to deflection is eliminated by the robust construction used, in which heavy cast ribbed sections are bolted and braced to form a unit of the strictest rigidity. Moreover, as these machines are of the undercrank type, the weight and build are low, affording maximum stability.

2. Die-Pressed Sintered Metal Components. Outlining the production and potentialities of high-strength sintered metal parts, a well-produced and illustrated 10-page booklet emphasizes the versatility of application of new powdered-metal processes, one of the advantages of which is that high-strength components can be manufactured with most of the characteristics of a casting or a forging.

Parts can be manufactured to a high degree of accuracy and to intricate shapes, virtually eliminating the need for subsequent machining operations, while the wide range of components which can be made by these processes is practically limitless, and includes complex parts for sewing machines, motor cars, office machinery, and armaments.

3. Sealed Rigid Ball Bearings. Details are contained in a well-produced and illustrated 8-page brochure of a range of prelubricated sealed rigid ball bearings with a life expectancy, under normal operating-speed and load conditions, of some 10,000 hours, without requiring any attention. The seal used has the twofold purpose of preventing escape of lubricant and entrance of dust, moisture, etc., and comprises sheet-metal washers to which a rubber washer is bonded during the rubber-curing process.

These bearings incorporate a number of important features. Thus, for instance, the assembly of rubber and sheet-metal washers is not force-fitted radially in grooves, thereby obviating the distortions of the outer races prevalent in similar types of construction. In addition, their construction is such that the oil leakages often experienced with similar bearing designs depending on metal-to-metal seals are completely eliminated.

4. Electronically Controlled Automatic Batch Weighing by Vibration. In the electronically controlled method of automatic weighing described in a neatly conceived 4-page brochure, a special electronic detector is used, this being connected to the appropriate circuits and relays on the weighing scales. The electronic detector controls a vibratory feeder, which conveys the material to be weighed from a supply hopper into a container. Weighing starts with feeding at the maximum rate, this being automatically reduced to a trickle just before the pointer registers the required weight. When the exact weight is reached, feeding is stopped.

The method applies equally well to quantities ranging from a few ounces up to several tons. Furthermore, specially fitted and designed machines are available for " difficult " materials, such as rolled oats, soap flakes, nails, etc., while a great variety of combinations are possible, including link-up with other machines, e.g., mixers, for automatic control.

5. Direct-Reading Instrument for Measuring Magnetic Fields. Designed to measure variations in the magnitude of the field of a television focus magnet, an interesting direct-reading instrument, described and illustrated in a 2-page pamphlet, is also eminently useful for the investigation of permanent magnets and the measurement of stray fields of transformers and electromagnets. In addition, it has also been found suitable for examining the fields of the large focusing electromagnets associated with particle accelerators.

The instrument has extremely high sensitivity, a tenfold increase in which is obtainable by a front panel switch. Three normal ranges are available, i.e., 0 to 5 oersteds, 0 to 50 oersteds, and 0 to 500 oersteds. All these ranges can be obtained with the general-purpose probe supplied with the instrument and may be selected at will ; if desired, they can, however, be extended by the use of a special probe. By virtue of its special design and construction, the instrument can be operated for long periods without any danger of drift in the amplifier and oscillator units.

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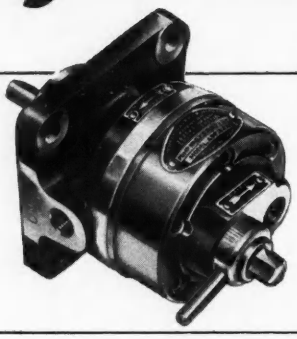

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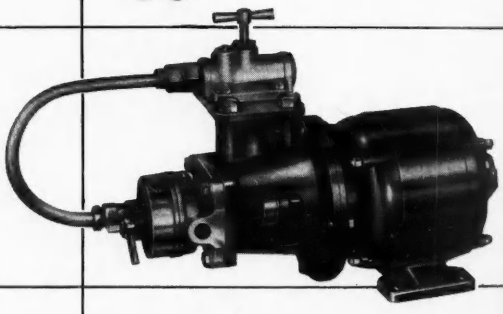

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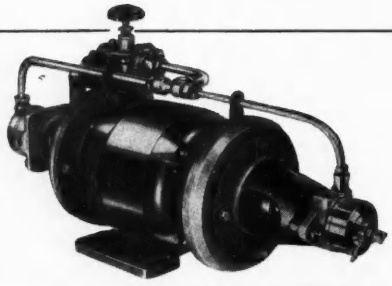

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